Evaluating the DBH Verification Method to Complex Buildings Designed According to New Zealand Compliance Documents C/AS1

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ABSTRACT

Performance-based fire engineering design is becoming a more common practice for fire safety design of large complex buildings and modifying existing buildings. However, different engineering assumptions and ambiguous acceptance criteria not only lead to inconsistent level of safety, but also cause inefficient Building Consent process and can result in expensive appeals. Currently in New Zealand, there is no detailed regulatory guideline available for performance-based fire engineering design.

In response to these concerns, in August 2006 the New Zealand Department of Building and Housing (DBH) has been developing a Verification Method (C/VM2) for demonstrating compliance with the Fire Safety requirements of the New Zealand Building Code (C Clauses). The proposed C/VM2 was released for the public comments in September 2010. It is expected to introduce greater transparency and less ambiguity for fire engineering designs through explicit guidance on fire scenarios, design fire inputs, evacuation parameters and performance criteria to be met in order for the design to be deemed compliant with the Building Code.

By applying C/VM2, the verification procedure can be determined in a more systematic way which benefits both designers and their clients to minimize disputes with building consent authorities and further reduce cost by reducing delays in constructions. Even though, in some measure the proposed C/VM2 may limit the freedom of designers, it still permits flexibility and innovation in design. The proposed C/VM2 is intended to provide a consistent and similar level of safety to that of New Zealand Compliance Documents – 'Acceptable Solution C/AS1', rather than alter the level of safety that the society currently accepts.

The proposed C/VM2 has been developed and revised as a result of analyses of a number of model buildings, but has not been comprehensively tested on complex buildings with assembly or disable occupancies. The objective of this research is to evaluate the proposed C/VM2 (version for field testing[1]) on four complex buildings, including Multi-level Night Club (SFPE case study 2010[2]), Hospital, Shopping Mall (SFPE case study 2000[3]) and Retail Warehouse. As the proposed C/VM2 is intended to deliver a similar level of safety as C/AS1, it is interested to see if C/AS1 compliant buildings can still meet the performance criteria in the proposed C/VM2. Hence, all case study buildings were designed to have fire safety features required in C/AS1. By applying C/VM2, the buildings are expected to meet all performance criteria against each of the fire scenarios prescribed in C/VM2. The results of this research may provide useful feedbacks to DBH on the suitability of the proposed verification method.

It has showed that the C/VM2 successfully implements a systematic and less ambiguous guidance for the future performance-based fire safety designs. It impels the decision on what is the acceptable level of safety moved from individuals to the authorities. In general, through intensive analyses, the proposed C/VM2 provides reasonable consistence with C/AS1 that all case study buildings pass the performance measurements pre-described in C/VM2 with the achieved safety factor of 1.0 for Fire Scenario 1.

The shortcomings revealed by this research indicate that even though the proposed C/VM2 is expected to be applicable for all types of complex building features or systems, it has not provided a detailed design solution for hospital buildings; in some cases, the design fire specified in C/VM2 is very severe that visibility drops too quickly in relative small spaces with low ceilings, e.g. the nightclub building and office block in the retail warehouse; On the other hand, it has relaxed criteria for buildings with sprinkler system; it may need more details on the egress analysis, e.g. evacuation for patients in the hospital buildings.

The continued analysis and development is necessary for a sound systematic verification method for performance-based fire engineering design. Even though there is no easy answer, the question of how detailed the performance-based designs to be regulated shall be answered before such a document is developed. One of the advantages of performance-based design over prescriptive requirements is its variation and flexibility, and thus the benefit of cost effective, whereas the disadvantage of giving too much freedom to individuals. Hence, the author feels it is vital to reach mutual agreement between designers and regulators to keep the balance of flexibility and cost-effectiveness while providing consistent level of safety and regulatory control for specific engineering design in the long term. It is suggested that the verification documents shall be developed in a balanced way where verification procedure and methods are specified for more consistent level of safety, as well as remain innovation and flexibility of fire engineering designs, thus not over limit the freedom of designers and disturbing the technological development. Hence, a solely deterministic method may not be the best solution that a risk-based concept is suggested to be incorporated into the new generation of the C/VM2.

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NOMENCLATURE

Abbreviations

ASET	Available Safe Egress Time (s)
BCA	Building Consent Authority
BSI	British Standards Institute
BWOF	Building Warrant of Fitness
C/AS1	Compliance Documents for New Zealand Building Code Clauses C1, C2, C3, C4 Fire Safety
C/VM2	Verification Method Framework for Fire Safety
CCC	Code Compliance Certificate
CFD	Computational Fluid Dynamics
DBH	New Zealand Government – Department of Building and Housing
DFS	Design Fire Scenario
F	C/AS1 Firecell Rating (minutes)
FDS	Fire Dynamic Simulator
FED	Fractional Effective Dose
FHC	C/AS1 Fire Hazard Category
FI	Flammability Index
FLED	Fire Load Energy Density (MJ/m^2)
FRR	Fire Resistance Rating (minutes)
FSP	C/AS1 Fire Safety Precautions
HD	Heat Detector
IFEG	International Fire Engineering Guidelines
IQP	Independent Qualified Person
MCP	Manual Call Point
NZBC	New Zealand Building Code
NZFS	New Zealand Fire Service
PBD	Performance-Based Design
PIM	Project Information Memorandum
PG	C/AS1 Purpose Groups

RSET	Required Safe Egress Time (s)
RTI	Response Time Index
S	C/AS1 Structural Endurance Rating (minutes)
SD	Smoke Detector
SDI	Smoke Development Index
SF	Safety Factor
SF_{co}	Safety Factor for FED CO
SF_{rad}	Safety Factor for FED Thermal Radiation
SF_{vis}	Safety Factor for Visibility
SFI	Spread of Flame Index
SFPE	Society of Fire Protection Engineers
SPK	Sprinkler

Symbols

Y_{soot}	Soot yield (kg/kg)
Y_{CO}	CO yield (kg/kg)
$\dot{q}_{VL}$	Ventilation limited heat release rate (kW)
A_o	Sum of the areas of all openings (m)
h_o	Average height for all openings (m)
t_d	Detection time determined from deterministic modelling (s)
t_n	Time from detection to notification of the occupants (s)
t_{p-e}	Time from notification until evacuation begins (s)
t_{travel}	Time spent moving toward a place of safety (s)
t_{flow}	Time spent in congestion controlled by flow characteristics (s)
T_{act}	Activation time (s)
t_{pre}	Time from detection until evacuation begins (s)
S	Horizontal travel speed (m/s)
D	Occupants density (persons/m^2)
F_c	Calculated flow (people/min)
W_e	Effective width of component being traversed (m)

CHAPTER 1 INTRODUCTION

1.1 Background

Since early of 1990s, Performance-based design (PBD) has been the epithet throughout the fire safety community. In one of the many respects, the increasing scientific knowledge and computer-based analytical methods contribute to the movement to performance-based design[4]. It has been adopted around the world as a methodology for maintaining fire safety in buildings while improving design flexibility and reducing cost.

The dramatic shift in thinking from the traditional 'code compliance' approach to a 'goal-oriented systems' approach began since early 1970s[5]. New Zealand was one of the first countries to adopt a performance-based building code (1992). The relevant Clauses in the Code for Fire Safety in buildings are C1, C2, C3 and C4[6] (Refer to APPENDIX A), which specify the objectives, minimum functional requirements and performance objectives, including:

- Protect occupant life safety;
- Protect neighbouring property;
- Provide for firefighter search and rescue activities;
- Protect the environment from adverse effects of fire.

Compliance with the New Zealand Building Code (NZBC) can be achieved in any one of three different ways: Verification Method, Acceptable Solution and Alternative Solution. A Verification Method is an approved calculation method, generally consisting of well established codes of practice for design[7]. No verification method has been approved for fire design. In New Zealand, the current fire design solutions are either following the Compliance Documents C/AS1, or providing an alternative solution based on performance-based fire engineering design. The advantage of C/AS1 is that design requirements are fully prescribed in prescriptive terms. Designs are straightforward and normally no detailed calculations are required. However, the disadvantage is that there is little scope to tailor designs to meet the specific requirements for complex buildings or modify existing buildings, which may result in costly over design. Therefore, it is now becoming more common practice to carry out a performance-based design, which is intended to be more innovative, flexible and normally cost-effective.

However, as performance-based design is focused on what is to be achieved but not how, this allows designers substantial freedom, but at the cost of shifting social fire safety goals to individuals[8]. Different engineering assumptions and ambiguous acceptance criteria will lead to inconsistent level of safety for similar type of buildings. Also, if individuals are allowed to freely choose fire safety levels it is possible that many would choose a level considerably lower than regarded as appropriate from a societal view point[9]. On the other hand, this also causes inefficient Building Consent process and can result in expensive appeals when there are disputes between designers and regulatory authorities. Therefore, there is often a considerable need for guidance in order to avoid arbitrariness and variation in quality and level of safety for performance-based design.

In response to these concerns, the Department of Building and Housing (DBH) has been working with the building industry, including fire engineers, the New Zealand Fire Service (NZFS) and Building Consent Authorities (BCA) to create a clearer and more robust set of requirements for fire design[10]. The key features of the proposed requirements include:

- A re-written Building Code Clauses C for fire safety, with explicit performance and acceptance criteria for protection from fire;
- A new Verification Method that would set out a clear method for specific designs to comply with the Building Code;
- A revised Acceptable Solution containing essential elements for fire safety for non-complex buildings.

The proposed new Code Clauses C addresses the following aspects of protection from fire:

- Ensuring a low probability of igniting combustible materials;
- Maintaining tenable conditions on escape routes until the building occupants have evacuated;
- Avoiding fire conditions approaching flashover from surface lining materials;
- Preventing fire spread to other properties.

The proposed changes were released for public comments in September 2010. The proposed Verification Method for Fire Safety C/VM2 delivers clear guidance on fire scenarios, design fire parameters, occupant pre-movement times, and performance criteria that are used for fire engineering assessment. It will benefit the building industry by streamlining the design process, reducing uncertainty for designers and minimizing disputes with BCA. There will be cost savings through reduced delays in construction and occupying buildings, and the potentials for increased innovation.

Obviously, the proposed C/VM2 will greatly affect the ways that current fire designs are carried out. The suggested approach for fire engineering design, compared to the current practice, is shown in Figure 1.1[11]. Under the current approach, fire engineer recommends the design fire scenarios, design fire parameters and performance criteria for assessing the fire safety of the proposed design. Under C/VM2 for a performance-based fire design, the building will have to be assessed against ten specified fire scenarios to ensure that various challenges to the building have been analysed. The design will be evaluated against the performance criteria published in the proposed C/VM2.

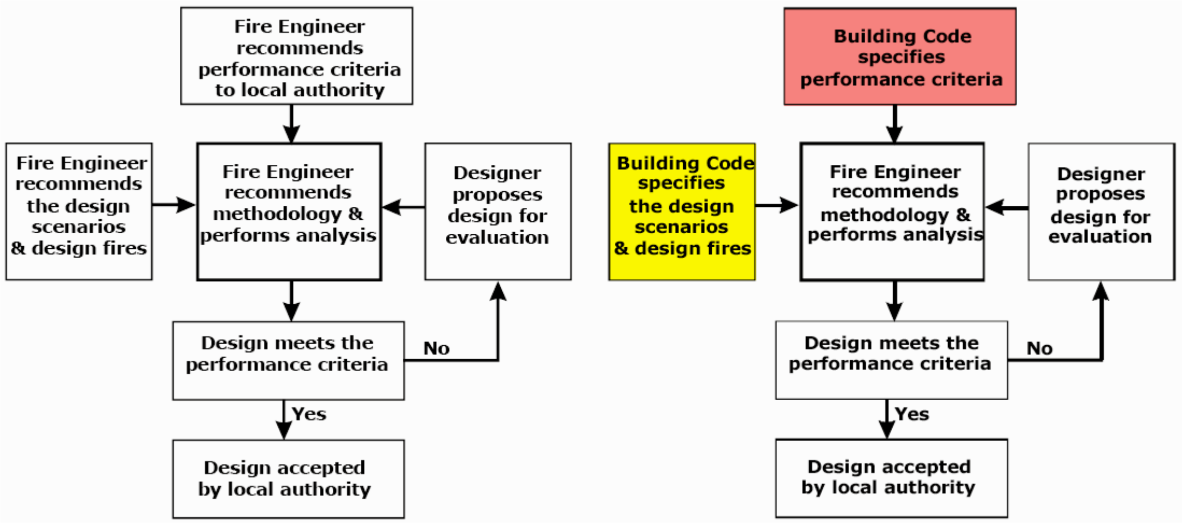


Figure 1.1: Current fire design process (left) vs. suggested approach in proposed C/VM2 (right)

1.2 New Zealand Regulatory Background

In New Zealand, the Building Act 2004[12] provides the mandatory framework for the building control system. It repealed the previous Building Act 1991 and dissolved the Building Industry Authority (BIA). Administration of the Building Act then shifted to the Department of Building and Housing (DBH), which was established on 1 November 2004. The Act has five parts:

- Part 1: Purpose and principles of the Building Act;
- Part 2: Matters relating to the Building Code and building work such as building consents;
- Part 3: Functions, duties and powers of the chief executive of the Department of Building and Housing and other regulatory authorities;
- Part 4: Matters relating to the licensing and disciplining of building practitioners;
- Part 5: Miscellaneous matters such as offences, criminal proceedings etc. and the transitional provisions from the previous Building Act 1991 to the Building Act 2004.

Building Regulations are made under and in accordance with the Building Act. The Building Code is contained in the Building Regulations and sets out performance criteria that building work must meet. The New Zealand Building Code is performance-based, which does not prescribe how a building work should be done but how it should perform. It consists of two preliminary clauses and 35 technical clauses. Each technical clause contains:

- Objective – The social objective that completed building work must achieve;
- Functional requirement – What the completed building work must do to satisfy the objective;
- Performance criteria – Qualitative or quantitative criteria which nominate how far the completed building work must go in order to comply.

Compliance Documents are produced by the Department of Building and Housing (DBH) to help people meet the requirements of the Building Code. They contain Acceptable Solutions (step-by-step building methods) and Verification Methods (calculations or test). There are 35 Compliance Documents, one for each Building Code clause. Buildings built to the method of Acceptable Solution or Verification Method described in a Compliance Document are automatically deemed to comply with the Code.

The performance criteria in the Building Code for Fire Safety (C Clauses) can be achieved by either following C/AS1, or alternative solutions. C/AS1 is not mandatory but provides one means of complying with the Code. Other than the C/AS1, alternative solutions can be used provided that they can be demonstrated to meet the required performance in the Building Code. An alternative solution can include a material, component or construction method that differs partially or even completely from those described in the Compliance Documents.

To ensure that building work is safe, durable and does not endanger health, except those 'exempt work' set out in the Building Act (Schedule 1), all building work shall meet the following requirements:

- Project information memorandum (PIM)
- Building consent
- Inspections
- Code compliance certificate
- Compliance schedule
- Building warrant of fitness

The procedure may include:

- Fill in the building consent application;
- The application is assessed and the building consent may be granted by Building Consent Authorities (BCA);
- The building is inspected by Independent Qualified Person (IQP);
- The building consent process is not complete until a Code Compliance Certificate (CCC) has been issued. A Code Compliance Certificate is issued by the Council once all information is provided and is correct, and that all building work complies with the building consent;
- A compliance schedule is required which details the inspection, testing and maintenance procedure;
- At last, a building warrant of fitness (BWOF) is issued which verifies the procedure set in the compliance schedule and must be renewed annually.

1.3 Performance-Based Design in other Countries

Performance-based codes were being developed in a number of countries. However, fire safety engineering still lacks a common framework for performance-based design. This is due to the lack of common definitions, test methods, verification methods, as well as other non-technical issues, which prompt different countries to adopt different regulatory approaches[4].

1.3.1 Sweden

Sweden went from a highly prescriptive building code to a function-based building code in 1994[13]. The regulations introduced the possibility to use alternative solutions provided that the solution was properly verified. However, no guidelines on verification were provided. Therefore, since 2006 the National Board of Housing, Building and Planning started the revision with the main objective to create a fire safety code with well defined levels of performance and clear purpose[14].

The process of fire safety engineering, according to the proposed Swedish guideline, contained three steps: (1) Risk identification; (2) Determining the need of verification; and (3) Verification of performance. The process should be iterative until performance can be verified. The performance level was identified in two ways. The preferred way is by defining quantitative performance criteria for specific sub-systems and design situations. The other way is to define one or a set of acceptable solutions that fulfil the operative requirements.

Three verification methods were proposed: (1) Qualitative assessment; (2) Deterministic scenario analysis; and (3) Quantitative risk assessment. A qualitative assessment is possible in cases where a few small deviations or one minor deviation is made compared to the acceptable solutions. The latter two methods may be used to evaluate any solutions that do not correspond with the acceptable solutions. The scenario based analysis will be covered by the guideline for a number of different situations. Scenarios as well as design fires will be evaluated based on works of NFPA 5000 and British standards.

1.3.2 UK

In the United Kingdom, the Building Regulations went through dramatic reform using functional or performance language instead of prescriptive requirements in 1985, thus reducing from 307 pages to only 23 pages[4]. The acceptance criteria and methods were not included in the regulation that engineers had the freedom to demonstrate compliance using performance criteria, safety factors, verification methods of their choice. However, many engineers still largely rely on the prescriptive guidance due to the complexities in gaining acceptance. Hence, there was a considerable need to provide a Code of Practice for fire engineering design. In 1989, a comprehensive Code of Practice on the application of fire engineering principles to fire safety of buildings was presented to British Standards Institution (BSI) and published in 2001 after a few years' review and update [15].

1.3.3 Australia

The Building Code of Australia (BCA) replaced its original prescriptive regulatory structure with a performance-based format in 1996[16]. After over ten years experience, one of the identified weakness is a gap between qualitative performance requirements and a verifiable solution due to lack of quantitative performance criteria. One of the solutions is a risk-informed performance-based approach[17]. Australia's future building code will be based on the existing performance-based BCA and mostly likely adopt a risk-informed approach, which determines building fire safety features based on assessing a building's relative importance to the wider or local community, as well as meeting objectives of life safety, prevention of fire spread and facilitation of fire fighting[18]. This approach could be very useful in Australia where public concerns are required to be addressed about fire safety in wildfire prone areas.

1.3.4 Canada

In September 2005, Canada adopted the world's first objective-based codes. In a performance-based regulatory system, the design is assessed against the objectives and performance requirements, so called 'first principle approach'. In Canada's objective-based regulatory system, the design is compared against the stated acceptable solutions, so called 'benchmark approach'[19]. The key components of the objective-based codes include:

- Objectives – state what the codes aim to achieve;
- Functional Statements – translate objectives into operational terms that describe the general conditions or outcomes to be achieved;
- Acceptable Solutions – describe one of the many possible solutions afforded under the objective-based code format;
- Intent Statements – describe in clear terms what an acceptable solution aims to achieve and explains the logical link that exists between this acceptable solution and its attributed objective(s) and functional statement(s);
- Application statements – describe the situations to which each code provision applies or does not apply, and thus help define the scope of the codes;
- Alternative Solutions – designate all possible alternative designs, materials or systems to those described in the acceptable solutions.

The intended benefit of objective-based codes is that it is clearly focused on society's minimum performance expectations while attempting to accommodate innovative solutions by: (1) Clarify the scope of the codes; (2) Better explain the intent of the code provisions; (3) Make the codes easier to apply to existing buildings; (4) Encourage the development of new and innovative materials and systems.

1.3.5 Japan

In Japan, the Building Standard Law (BSL), a highly prescriptive building code system, is the main law that regulates building and their equipment since 1950[20]. In 1998 the BSL was revised to include performance-based design and enforced in 2000. The BSL retains the conventional prescriptive clause and performance-based clause in parallel. The fire safety provisions in the BSL have five main objectives: (1) Reduction of fire occurrence; (2) Evacuation safety; (3) Prevention of collapse; (4) Assurance of fire fighting; (5) Prevention of urban fire.

Performance-based requirements are set for two of the above: evacuation safety and prevention of collapse by fire. Performance-based design can be verified by two routes: verification by Notification, and approval by the Minister. The 'Notification' regulates the verification methods including input parameters such as fire loads, density of occupants for various use, calculation methods and criteria. Designers cannot modify the verification methods thus the flexibility are limited. The 'Approval by the Minister' is in the freedom to choose verification methods. The Minister judges if the applicant satisfies the functional requirements.

So far, there have been several problems on the evaluation method for the performance-based design, especially in respect to the evacuation safety, such as the differences in the rates of fire occurrence and casualty occurrence in fire have not been analysed[21]. On the other hand, according to BSL, the method to determine design fire is described according to occupancy type of room and interior finish. This design fire is only a representation of the numerous conditions of fires that are conceivable in actual fire[22]. Therefore, in Japan, a framework for performance-based design is under development based on risk concept.

1.3.6 Norway

In 1997, Norway removed the prescriptive fire safety requirements from the building code and described them in guidelines instead, which have since then been referred to as pre-accepted solutions to meet the functional fire safety requirements in the building regulations[23]. Those requirements can be satisfied by either using pre-accepted solutions or alternative solutions. Alternative solutions have to be verified by a fire safety engineer employed by an approved company. Both solutions can be regarded into two levels: the building fire safety design level where fire performance requirements are established; and the solution level where fire performance is fulfilled. The central building authority also pointed out how disagreements between the building fire safety designers and controller should be handled.

Based on the past experience, there are five main experiences have been pointed out regarding the alteration fire safety solutions. There is still a huge need of guidelines on choice of targets, methods and indicators to evaluate the fire performance of building fire designs.

- The building fire safety design documents are not possible to survey;
- Lack of consistency;
- Improper use of references;
- Fire safety targets and risk acceptance criteria are missing or not consistent;
- Improper verification of risk acceptance criteria.

1.3.7 South Africa

South Africa was one of the first countries to adopt a performance-based model for Building Code in 1987[24]. There are two ways to comply with the Functional Regulations: South African National Standard (SANS) which is equivalent to 'deemed-to-satisfy' method; and Rational Design which is the term given to performance-based design. As there is no detailed guideline for performance-based design, not mentioning those benefits, performance-based design is often viewed by developers and building owners as a cheap alternative to a compliant building, with cost being a major driving force behind the motivation.

Hence, the main challenges for performance-based fire design in South Africa include:

- Better education and training of both regulators as well as engineers;
- More objective measurement tools;
- More robust codes and guidance documents;
- Better regulatory bodies.

1.4 Objectives of Research

The proposed C/VM2 has been developed and revised as a result of analyses of a number of model buildings, but has not been tested on complex buildings with assembly or disable occupancies. The objective of this research is to evaluate the proposed C/VM2 (version for field testing[1]) on four complex buildings, including:

- Multi-level Night Club (SFPE case study 2010[2])
- Hospital
- Shopping Mall (SFPE case study 2000[3])
- Retail Warehouse

These case study buildings were chosen for this research because they all require specific design due to either complex structures or assembly / disable occupancies. The nightclub building has crowded occupancy and there are concerns for the combustible interior finishes; In the hospital building, occupants may require assistance for evacuation or even defending in place where evacuation is not possible or desirable; The shopping mall has complex building features such as large atria and open circulation which allows smoke / fire spread to other spaces and threatens large number of occupants; The retail warehouse contains large quantities of combustible materials stored in racks which may cause rapid fire spread.

As the proposed C/VM2 is intended to deliver a similar level of safety as C/AS1, it is of interest to evaluate if these C/AS1 compliant buildings can still meet the performance criteria in the proposed C/VM2. Hence, each case study building was designed to comply with C/AS1. Then, by applying C/VM2, the design is expected to meet all performance criteria against each of the ten fire scenarios. If a C/AS1 compliant building does not meet the C/VM2 criteria, the proposed C/VM2 may provide higher level of safety than that of C/AS1 for similar type of buildings.

As the level of safety of C/AS1 compliant buildings is only implicit which is not quantitatively specified and there is no ‘absolute’ level of safety established, this research does not intend to derive the level of safety inherent neither in C/AS1 or the proposed C/VM2.

1.5 Report Overview

Following the introduction, Chapter 2 gives a brief summary of the New Zealand Acceptable Solution C/AS1 for those readers who are not familiar with C/AS1. The proposed Verification Method C/VM2 is described and explained in details in Chapter 3. Chapter 4 introduces the methodology used to analyse each case study building. Generally, each building was firstly designed to comply with C/AS1. Then, verification method C/VM2 analysis was carried out to check if a C/AS1 compliant building could still meet the performance criteria set in the proposed C/VM2. Detailed analysis for each case study building is provided in Chapter 5 to Chapter 8 respectively, followed with a summary of results and discussion. Some extended analyses are provided based on those discussions at the end of each chapter. Two design strategies are provided for the nightclub building including both prescriptive C/AS1 design and a performance-based design in Chapter 5. Finally, Chapter 9 summarises the findings in this research as well as recommendations for the proposed C/VM2.

CHAPTER 2 SUMMARY OF ACCEPTABLE SOLUTION C/AS1

The acceptable solution C/AS1 provides one way, but not the only way, of satisfying the New Zealand Building Code (NZBC) Clause C for fire safety in buildings. The methods given in C/AS1 are particularly appropriate for simple, low-rise buildings. However, specific fire engineering design is required for buildings which have features or systems out of the scope of C/AS1[6]. This chapter gives a brief review of C/AS1 for those who are not familiar with. Readers shall refer to individual chapters of each case study building for detailed C/AS1 design. Other Compliance Documents used in conjunction with C/AS1 may include:

- D1/AS1 (2006) [25]: Access Routes
- F6/AS1 (2007) [26]: Visibility in Escape Routes
- F7/AS1 (2008) [27]: Warning Systems
- F8/AS1 (2006) [28]: Signs

2.1 Definitions

The acceptable solution C/AS1 has the following definitions:

Accessible route – An access route usable by a person with a disability. It shall be a continuous route that can be negotiated unaided by a wheelchair user. The route shall extend from street boundary or car parking area to those spaces within the building required to be accessible to enable a person with a disability to carry out normal activities and processes within the building.

Dead end – That part of an open path where escape is possible in only one direction.

Escape height – The height between the floor level in the firecell being considered and the floor level of the required final exit which is the greatest vertical distance above or below that firecell.

Escape route – A continuous unobstructed route from any occupied space in the building to a final exit to enable occupants to reach a safe place, and shall comprise one or more of the following open paths, protected paths and safe paths.

Exitway – All parts of an escape route protected by fire or smoke separations, or by distance when exposed to open air, and terminating at a final exit.

Final exit – The point at which an escape route terminates by giving direct access to a safe place. If a safe place can be reached only by passing down an alley, or across a bridge, the final exit is not reached until the end of such an alley or bridge.

Firecell – Any space including a group of contiguous spaces on the same or different levels within a building, which is enclosed by any combination of fire separations, external walls, roofs, and floors.

Fire door – A doorset, single or multi-leaf, having a specific fire resistance rating, and in certain situations a smoke control capability, and forming part of a fire separation. The door, in the event of fire, if not already closed, will close automatically and be self latching.

Firecell rating (F) – The fire resistance rating (FRR) intended to prevent fire spread to another firecell, for sufficient time to provide for safe evacuation of occupants and protection of adjacent household units and sleeping areas in the building of fire origin and firefighters engaged in fire fighting and rescue operations.

Fire hazard category (FHC) – The number (graded 1 to 4 in order of increasing severity) used to classify purpose groups or activities having a similar fire hazard, and where fully developed fires are likely to have similar impact on the structural stability of the building.

Fire load energy density (FLED) – The total fire load divided by the firecell floor area. In this calculation the floor area shall include circulation and service spaces, but exclude exit ways and protected shafts.

Fire safety precautions (FSPs) – The combination of all methods used in a building to warn people of an emergency, provide for safe evacuation, and restrict the spread of fire, and includes both active and passive protection.

Fire separation – Any building element which separates firecells or firecells and safe paths, and provides a specific fire resistance rating.

Flammability index (FI) – That index number for flammability, which is determined according to the standard test method for flammability of thin flexible materials.

Group sleeping area – A firecell containing communal sleeping accommodation for a specified number of people who may or may not be known to one another. Partial subdivision within the firecell is permitted with specific limitation including that no occupied space is fully enclosed and all occupied spaces are open and available to all occupants at any time. A group sleeping area firecell may include spaces for associated direct support functions, such as hygiene facilities and tea making (not cooking) activities, for use by the occupants. It does not include spaces, such as waiting rooms, lounges, dining rooms or kitchens, providing a communal service function for all occupants.

Limited area atrium – A single firecell in which individual occupied spaces at different levels open onto a common enclosed space. Limitations are placed on the number of intermediate floors (no more than two levels), individual floor areas and permitted occupant load, depending on the provisions for smoke detection, smoke control and the means of escape from fire.

Occupant load – The greatest number of people likely to occupy a particular space within a building.

Open path – That part of an escape route (including dead ends) within a firecell where occupants may be exposed to fire or smoke while making their escape.

Protected path – That portion of an exitway within a firecell which is protected from the effects of smoke by smoke separations.

Protected shaft – A space, other than a safe path, enclosed by fire separations or external walls used to house building services, lifts, or conveyors which pass from one firecell to another.

Purpose group – The classification of spaces within a building according to the activity for which the spaces are used.

Safe path – that part of an exitway which is protected from the effects of fire by fire separations, external walls, or by distance when exposed to open air.

Smokecell – A space within a building which is enclosed by an envelope of smoke separations, or external walls, roofs, and floors.

Smoke control door – A doorset with closefitting single or multi-leaves which are impermeable to the passage of smoke, fitted with smoke seals and installed within a smoke separation. The door, in the event of smoke, if not already closed, will close automatically and be held closed.

Spread of flame index (SFI) – That index number for spread of flame which is determined according to the standard test method for measuring the properties of lining materials.

Structural fire endurance rating (S) – The fire resistance rating (FRR) intended to prevent fire spread or structural collapse for the complete burnout of the firecell.

Suite – A firecell providing residential accommodation for the exclusive use of one person or of several people known to one another. It comprises one or more rooms for sleeping and may include spaces used for associated domestic activities such as hygiene and cooking. Bed numbers in a suite are limited to six in purpose groups SC and SD, or 12 in purpose group SA.

2.2 Design Procedures

Application of C/AS1 depends largely on the basic measurements such as building height, floor plans, wall openings and distances to relevant boundaries[6]. The document recommends that the following sequence be used as described in C/AS1.

Step 1. Determine the application of the Building Act. e.g. the project is for a new building, and alteration to an existing building, or a change of use of a building;

Step 2. Determine the owner's requirements;

Step 3. Determine the purpose groups and fire hazard categories (FHCs);

Step 4. Determine the number and distribution of occupants;

Step 5. Determine the means of escape from fire from all firecells. This can influence the floor plan and may require reassessment of Step 4;

Step 6. Determine the number of firecells for life safety, firecell (F) rating and fire safety precautions (FSPs);

Step 7. Determine any additional protection and structural fire endurance (S) ratings if required;

Step 8. Determine the fire resistance rating (FRR) of building elements including requirements for structural stability;

Step 9. Determine requirements for control of internal fire spread;

Step 10. Determine requirements for control of external fire spread;

Step 11. Determine requirements for firefighting;

Step 12. Determine requirements to control outbreak of fire.

2.3 Fire Hazard Categories

The Fire Hazard Category (FHC) is used to determine the structural fire endurance (S) ratings. It is categorized according to the Fire Load Energy Density (FLED). FLED is one of the factors affecting the fire severity and thus the impact of the fire on the building structure. Other important factors may include ventilation, surface area to mass ratio of the fuel, and its rate of building. FHC is chosen in preference to FLED (shown in Table 2.1) because it is better able to categorize certain spaces containing mainly low heat release rate fuels, e.g. frozen meat carcasses. The design value of FLED for each FHC is taken as the 80 percentile value of this range.

Table 2.1: Fire Hazard Category (FHC) in C/AS1

FHC	FLED (MJ/m^2)	Design Value of FLED (MJ/m^2)
1	0-500	400
2	501-1000	800
3	1001-1500	1200
4	>1500	Specific Design

2.4 Purpose Groups and Occupant Numbers

The purpose group and occupant loads are primary parameters in C/AS1 to determine the number and size of exitways and other fire safety precautions. Several purpose groups listed below are of particular interests for this research. The fire hazard category correlated to that purpose group is determined by the design value of FLED as shown in C/AS1 Table 2.1 (refer to APPENDIX B).

Crowd Activities

CS / CL – Crowd Small (occupant loads up to 100) or Crowd Large (occupant loads exceeding 100); Examples of building use are nightclubs, restaurants and eating places with cooking facilities etc.

CM – Crowd Mercantile; Examples are exhibition halls, retail shops and supermarkets etc.

Sleeping Activities

SC – Sleeping Care, where occupants require special care or treatment such as hospitals.

SA – Sleeping Accommodation, where people will be transient and reside for a temporary period, typically not more than 90 days, or where limited assistance or care is provided for principle users, such as motels, hotels, boarding houses / schools, community care institutions.

Working, Business or Storage Activities

WL – Working Low, where spaces for working, business or storage has low fire load. Examples are banks, offices, and hairdressing shops etc.

WM – Working Medium, where spaces for working, business or storage has medium fire load and fire grows up to 1 MW in 75 seconds. Examples are spaces manufacturing and processing of combustible materials or rack storage up to 3 m high (excluding foamed plastics).

WH – Working High, where spaces for working, business or storage has high fire load and fire up to 1 MW in 75 seconds. Examples are rack storage of combustible materials over 3 m high (excluding foamed plastics).

WF – Working Special Fire Hazard, where spaces for working, business or storage has medium / high fire load and ultra fast fire exceeds 1 MW in 75 seconds. Examples are areas involving significant quantities of highly combustible and flammable or explosive materials, or bulk storage warehouses for flammable materials or foamed plastics.

Intermittent Activities

IE – Exitways, refers to exitways on escape routes which are either protected path or safe path.

IA – Intermittent Activities, refers to spaces providing intermittently used support functions. Examples are car parking, garages, enclosed corridors, locker rooms, toilets and service rooms etc.

The occupant loads can be calculated from the occupant densities given in *C/AS1 Table 2.2* (refer to APPENDIX C) based on the floor area of the part of the building housing activity. The given occupant densities in *C/AS1 Table 2.2* already allow for a proportion of the floor area, appropriate to the activity being occupied by furniture, partitions, fixtures and associated equipment.

2.5 Means of Escape

2.5.1 Number, Height and Width of Escape Routes

Means of escape is an important part either for prescriptive or performance-based design. To comply with C/AS1, the number of escape routes from a floor level shall meet those requirements in *C/AS1 Table 3.1* (refer to APPENDIX D). Except that occupant load served by the escape route is no greater than 50 and length of escape route does not exceed the permitted travel distance, every occupied space in a building shall have at least two escape routes.

Clear height within escape route shall be no less than 2100 mm across the full width. Smoke control door or fire door opening within or giving access to any exitway shall have a clear height of no less than 1955 mm for the required width of the opening.

Escape routes shall provide sufficient width for the served occupant loads. It is determined by the combined width based on the occupant loads or minimum individual width whichever is greater (refer to APPENDIX E). Minimum individual width of 850 mm is required for horizontal travel and 1000 mm for vertical travel. Where there is no requirement to provide for people with disabilities, and occupant load is less than 50, width of escape routes for an open path, may be reduced to 700 mm for horizontal travel, and 850 mm for vertical travel. The width of an escape route within an exitway shall be no less than 1000 mm. Doors within exitways shall reduce the minimum exitway width by no more than 125 mm.

Some other factors need to be considered for calculating the width of escape route, such as horizontal or vertical travel and whether or not the building is sprinkler protected. For either combined or individual escape routes, vertical travel requires wider escape routes than horizontal travel. Meanwhile, if a building is not sprinkler protected, total width of escape routes shall still be available with one of the escape routes being considered unusable.

Time for evacuation not only depends on the capacity of escape route but also the travel distance. Escape routes comprise one or more of the open paths, protected paths and safe paths, all of which shall meet the requirements in *C/AS1 Table 3.3* (refer to APPENDIX F). The permitted travel distance is allowed to increase based on the type of detection / suppression systems as shown in Table 2.2. However, where more than one FSPs are provided, the combined increase shall not exceed 200%, and no increase is allowed for sleeping occupants under care (i.e. purpose group SC or SD).

Table 2.2: Permitted increases of travel distance in open path and horizontal safe path in C/AS1

FSPs	**PG**	
	SA, SR or SH	**CS, CL, CM, ML, WM, WH, IA, ID**
Heat detectors	10%	20%
Smoke detectors (Type 4, 5 or 7 as in APPENDIX G)	50%	100%
Sprinklers	50%	100%

2.5.2 Doors Subdividing Escape Routes

Doors subdividing escape routes shall comply with all the following requirements addressed in *Clause 3.17 C/AS1*.

- Doors into the safe path stairways and at the final exits, are to be hinged or pivoted on one vertical edge only, self-latching and self-closing;
- Doors subdividing escape routes are required to open in the direction of escape if there are more than 20 occupants using the doors (or 10 into and within an exitway);
- All exit door-locking devices should be clearly visible, located where such a device would be normally expected, designed to be easily operated without a key or other security device, and allow the door to open in the normal manner;
- Self-closing device shall be active at all times, or activated by releasing a hold-open device in response to operation of a smoke detector;
- Hold-open devices shall be fitted to fire doors or smoke control doors. Fire detectors for releasing hold-open devices shall be smoke detectors.
- Fire doors shall comply with all the requirements in *AS/NZS 1905.1: Fire Resistant Doorsets*.

Doors in open paths shall provide an unobstructed opening width of no less than 760 mm, and when multi-leaf, have no single leaf less than 500 mm wide. The minimum door opening width may be reduced to 600 mm where it is not required to be an accessible route. Doors within exitways (including entry and final exit doors), reduce the minimum exitway width by no more than the 125 mm and open no less than 90^{o}.

2.5.3 Signage

Signs on escape routes shall comply with all the requirements in *F8/AS1: Signs* to:

- Be provided in sufficient locations to identify escape routes and guide people to a safe place;
- Remain visible in the event of a power failure of the main lighting supply.

Exit signs shall be located:

- At each point in the open path where a door giving access to a final exit or an exitway is not visible in normal use; and positioned on the leaf at or above handle height, or on a vertical surface within 600 mm of the door;
- To clearly indicate each door giving access to a final exit or an exitway; and
- To clearly identify the route of travel through the exitway.

Exit signs shall be provided with external or internal lighting, or the sign may be self-luminous to be visible at all times.

Every doorset required to possess fire or smoke stopping capabilities shall have a sign fixed to both sides of the door leaf adjacent to the handle or push plate, stating “Fire Door, Please Keep Closed”, except that doors fitted with hold open devices shall have a sign stating only “Fire Door” or “Smoke Control Door”.

2.5.4 Emergency Lighting

Emergency lighting shall comply with requirements in *F6/AS1: Visibility in Escape Routes* to help safeguard people from injury in escape routes during failure of the main lighting. Emergency lighting must be provided in all of the following:

- In all exitways; and
- At every change of level in an escape route; and
- In an escape route from the point where the initial open path travel distance exceeds 20 m; and
- In any occupied space designed for an occupant load of more than 250 people including all escape routes serving that space; and
- In any part of an escape route designed to serve more than 250 people.

2.6 Fire Safety Precautions (FSPs)

A building may comprise one or more firecells to make sure there is sufficient time for evacuation, and meantime prevent fire spreading to other firecells or adjacent buildings. Generally, except for single-story buildings, C/AS1 requires at least each floor is a separate firecell. A floor may be sub-divided into several firecells to control fire spread, or where an unsprinklered firecell floor area exceeds the limits shown in Table 2.3. Where a firecell is sprinklered, the firecell floor area may be unlimited.

Table 2.3: Firecell floor area limits in C/AS1

FHC	Maximum Firecell Floor Area (m^2)
1	5000
2	2500
3	1500
4	Specific Design

Fire safety precautions (FSPs) are determined for individual firecells and vary according to the purpose group contained and the escape height. It increases with increases in occupant load and escape height. FSPs within firecells shall ensure occupants have reasonable warning and protection while making their escape to a safe place; the spread of fire is restricted; and Fire Service has sufficient time to undertake rescue operations. *C/AS1 Table 4.1* (refer to APPENDIX G) lists the FSPs as well as firecell ratings (F) of individual firecells according to different purpose groups, occupant loads and escape heights. However, FSPs for the whole building are subject to adjustment where specific clauses apply in other parts of C/AS1.

2.7 Control of Internal and External Fire Spread

Control of internal fire spread can be achieved by several methods depending on the purpose groups and their activities, including:

- Subdividing firecells into smaller firecells or smokecells;
- Separating high risk activities from others, especially from sleeping purpose groups;
- Ensuring the integrity of construction joints and closures in fire and smoke separations;
- Preventing fire and smoke spreading through concealed spaces and services ducts;
- Using appropriate materials and surface finishes;
- Installing fire suppression systems.

Fire can spread vertically up external walls via combustible external cladding etc. or horizontally by thermal radiation or structural collapse. The vertical fire spread may be controlled by installing fire rated spandrels, aprons or sprinklers. The horizontal fire spread may be controlled by distance separation, limiting unprotected areas in external walls, using fire resisting glazing etc.

CHAPTER 3 THE PROPOSED VERIFICATION METHOD - C/VM2

3.1 Background

In New Zealand, the Building Act 2004[12] requires the current Building Code to be reviewed to ensure that performance standards are clear, and meet the new purpose and principles set out in the Act. As part of the review, the Department of Building and Housing (DBH) in New Zealand has been developing a new framework "Verification Method C/VM2 Framework for fire safety" [29] for fire engineering design to demonstrate compliance with the Building Code Clauses C: Fire Safety[6]. The proposed C/VM2 (briefing for field testers) was initially published for public comments on September 1, 2009, while this research was carried out based on this very first version. It has been continuously reviewed and updated based on feedbacks from field testers and a number of recognized experts involved in the project.

The proposed C/VM2 still permits flexibility and innovation in design, but ensures consistency between designs for very similar uses. This provides a mechanism for the regulator to exercise control over the level of fire safety that must be achieved in buildings, without having to go through a formal process to calculate expected fire losses on a building-by-building basis. It aims to introduce greater transparency and less ambiguity for fire engineering designs through explicit guidance on fire scenarios, design fire inputs, evacuation parameters and performance criteria. By applying the framework, it is intended to provide a consistent and similar level of safety to that of New Zealand Acceptable Solution C/AS1, rather than alter the level of safety that the society currently accepts. In order that a consistent solution is provided, the proposed C/VM2 must be used in its entirety.

3.2 General Principles

All building designs will be assessed against ten specified fire scenarios to ensure that a range of different types of challenges to the building have been explored in the design. The fire scenarios have been developed to ensure that the elements of building design, that are currently regulated in the Compliance Documents, continue to be addressed in a performance-based design. The design fires are specified for the applicable scenarios (some scenarios may not require detailed analysis) thus designers are not required to develop design fire inputs for fire engineering analysis.

The design procedure using the proposed C/VM2 is shown in Figure 3.1. Firstly, complete the preliminary trial design following the Design Brief process as outlined in the International Fire Engineering Guidelines (IFEG) [30]. Then, apply the specific design fire scenarios with appropriate design fires, human factors, and calculation methods to the trail design. For those scenarios that require detailed assessment, compare the outputs with the acceptance criteria specified in the C/VM2. If all applicable acceptance criteria are met, the design is code compliant. If not, designers shall make changes to the trial design and the process may be repeated until the design meets the acceptance criteria.

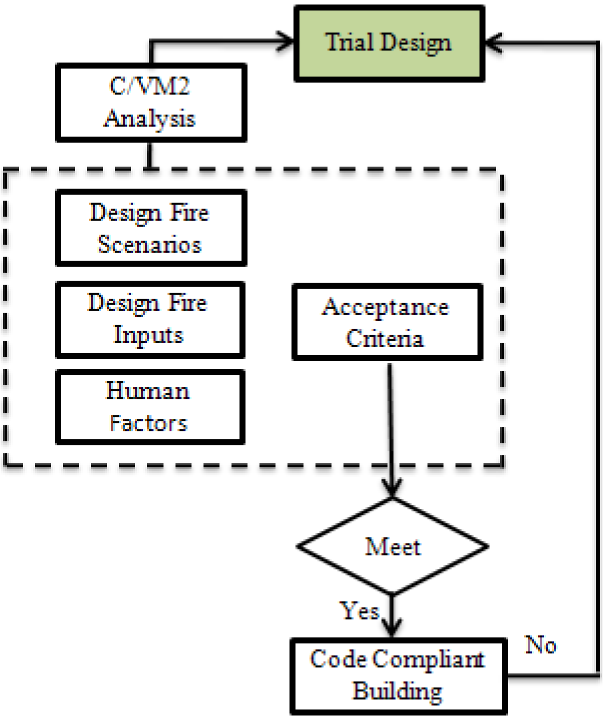


Figure 3.1: Flow chart showing the verification process using the proposed C/VM2

The proposed C/VM2 does not presume or require the use of any particular fire models or methodologies. Designers shall choose and defend appropriate methodologies used in the fire engineering design. For example, Design Fire Scenario 1 requires designers to demonstrate that there is sufficient time for all occupants to escape in case of fire, in fire engineering terms the available safe egress time (ASET) is greater than the required safe egress time (RSET). The available safe egress time (ASET) is defined as the whole time from fire ignition to the time untenable condition occurs in the evacuation route, and the required safe egress time (RSET) is the time required for occupants to reach an area of safety[31]. The methodologies shall account for the fire and egress inputs required to be used by the proposed C/VM2 such as design fire parameters and pre-movement times, etc.

3.3 Performance Groups of Buildings

Where a risk-informed approach may be adopted, the proposed C/VM2 categorizes buildings in accordance with their importance by assigning them to Performance Groups (PG) on a scale where less important buildings such as sheds and minor storage facilities fall into PG 1, while more important buildings such as hospitals fall into PG 4 as shown in Table 3.1.

Table 3.1: Performance Groups (PG) of buildings in the proposed C/VM2

PG	Building Types	Specific Structures
1	Buildings posing low risk to human life or environment, or a low economic cost, should the building fail.	▪ Non-habitable buildings, e.g. sheds, barns; ▪ Minor storage facilities; ▪ Back country huts.
2	Buildings posing normal risk to human life or environment, or a normal economic cost, should the building fail.	Residential, commercial and industrial buildings not listed in other PGs.
3	Buildings of an increased level of societal benefit or importance, or with higher levels of risk-significant factors to building occupants. *(These buildings have increased levels of performance as they may house large number of people, vulnerable populations, or occupants with other risk factors, or fulfil some roles of increased importance to the local community or to society in general.)*	▪ Buildings where more than 300 people congregate in one area; ▪ Buildings with primary school, secondary school, or early child care facilities with a capacity greater than 250; ▪ Buildings with tertiary or adult education facilities with a capacity greater than 500; ▪ Health care facilities with a capacity of 50 or more residents but not having surgery or emergency treatment facilities; ▪ Jails and detention facilities; ▪ Any other building with a capacity of 5000 or more people; ▪ Buildings for power generating facilities, water treatment for potable water, waste water treatment facilities, and other public utilities facilities not included in PG 4. ▪ Buildings not included in PG 4 or PG 5 containing sufficient quantities of highly toxic gas or explosive materials capable of causing acutely hazardous conditions that do not extend beyond property boundaries.
4	Buildings that are essential to post-disaster recovery or associated with hazardous facilities.	▪ Hospitals and other health care facilities having surgery or emergency treatment facilities; ▪ Fire / rescue / police stations, and emergency vehicle garages; ▪ Designated emergency shelters; ▪ Designated emergency preparedness, communications, and operation centres and other facilities required for emergency response;

PG	Building Types	Specific Structures
		▪ Power generating stations and other utilities required as emergency backup facilities for PG 3 structures; ▪ Buildings housing highly toxic gas or explosive materials capable of causing acutely hazardous conditions that extend beyond property boundaries; ▪ Aviation control towers, air traffic control centres, and emergency aircraft hangars; ▪ Buildings having critical national defence functions; ▪ Water treatment facilities required to maintain water pressure for fire suppression; ▪ Ancillary buildings required for operation of PG 4 structures during an emergency. *(including, but not limited to, communication towers, fuel storage tanks or other structures housing or supporting water or other fire suppression material or equipment)*
5	Buildings whose failure poses catastrophic risk to a large area (e.g. 100,000m^2) or a large number of people (e.g. 100,000 people).	▪ Major dams; ▪ Extreme hazard facilities.

Buildings with higher PG are required to survive a higher magnitude event than those with lower PG as shown in Table 3.2. Buildings shall perform in a way that reflects its importance in the event of fire. For example, a shed could be destroyed provided people are safe and adjacent properties are not damaged, while a hospital's functionality shall remain unaffected even though a fire has occurred in one space. To meet the performance objectives, the tolerable impacts in respect of occupants and fire locations are shown in Table 3.3.

*Table 3.2**:** Relationship of performance groups, design events and associated tolerable impacts*

Design Event	Frequency of Occurrence	Performance Groups			
		PG 1	**PG 2**	**PG 3**	**PG 4**
Very Large	Very Rare	Severe	Severe	High	Moderate
Large	Rare	Severe	High	Moderate	Mild
Medium	Seldom	High	Moderate	Mild	Mild
Small	Moderate	Moderate	Mild	Mild	Mild

*Table 3.3**:** Tolerable impacts in respect of occupants and fire locations*

Locations	Performance Groups			
	PG 1	**PG 2**	**PG 3**	**PG 4**
Occupants	No impact	No impact	No impact	No impact
Room of fire origin	Destroyed	Destroyed	Major damage	Temporary loss of function
Rest of building	Destroyed	Destroyed	Mild	No impact
Adjacent property	Minor cosmetic damage	Minor cosmetic damage	Minor cosmetic damage	Minor cosmetic damage

3.4 Design Fire Scenarios (DFS)

Ten fire scenarios are specified in the proposed C/VM2 which are loosely based on those in NFPA 5000 Clause 5.5.2[32]. The NFPA 5000 presently deals with eight design fire scenarios:

- **Design Fire Scenario 1** – which is an occupancy-specific design scenario representative of a typical fire for the occupancy, shall explicitly specify:
  1) *Occupant activities;*
  2) *Number and location of occupants;*
  3) *Room size;*
  4) *Furnishings and contents;*
  5) *Fuel properties and ignition sources;*
  6) *Ventilation conditions;*
  7) *First item ignited and its location.*

- **Design Fire Scenario 2** – which is an ultrafast-developing fire in the primary means of egress, with interior doors open at the start of the fire, shall address the concern regarding a reduction in the number of available means of egress;

- **Design Fire Scenario 3** – which is a fire that starts in a normally unoccupied room that can potentially endanger a large number of occupants in a large room or other area, shall address the concern regarding a fire starting in a normally unoccupied room and migrating into the space that can, potentially, hold the greatest number of occupants in the building;

- **Design Fire Scenario 4** – which is a fire that originates in a concealed wall space or ceiling space adjacent to a large, occupied room, shall address the concern regarding a fire originating in a concealed space that does not have either a detection system or suppression system and then spreading into room within the building that can, potentially, hold the greatest number of occupants;

- **Design Fire Scenario 5** – which is a slow-developing fire, shielded from fire protection systems, in close proximity to a high occupancy area, shall address the concern regarding a relatively small ignition source causing a significant fire;

- **Design Fire Scenario 6** – which is the most severer fire resulting from the largest possible fuel load characteristic of the normal operation of the building, shall address the concern regarding a rapid-developing fire with occupants present;

- **Design Fire Scenario 7** – which is an outside exposure fire, shall address the concern regarding a fire starting at a location remote from the area of concern and either spreading into the area, blocking escape from the area, or developing untenable conditions within the area;

- **Design Fire Scenario 8** – which is a fire originating in ordinary combustible in a room or area with each passive or active fire protection system or fire protection feature independently rendered ineffective, shall address the concern regarding each fire protection system or fire protection feature, considered individually, being unreliable or becoming unavailable. This scenario shall not be required to be applied to fire protection systems or fire protection features for which both the level of reliability and the design performance in the absence of the system or feature are acceptable to the authority having jurisdiction.

The design fire scenarios in the proposed C/VM2 have been expanded to cover fire spread to neighbouring property, external vertical fire spread, interior surface finishes and fire-fighting facilities. The scenarios for external vertical fire spread and interior surface finishes have been added to specifically address fire scenarios currently dealt with in C/AS1. The ten design fire scenarios are summarised as follows in Table 3.4.

Table 3.4: Ten fire scenarios prescribed in the proposed C/VM2

Scenarios	Comments
DFS 1 – Challenging Fire	an occupancy-specific design scenario and design events depend on purpose group and fire hazard category
DFS 2 – Blocked Exit	a fire considered to block a primary means of escape
DFS 3 – Fire in Unoccupied Room	a fire that starts in a normally unoccupied room that can potentially endanger a large number of occupants in another room
DFS 4 – Fire in Concealed Space	a fire that starts in a concealed space that can potentially endanger a large number of occupants in another room
DFS 5 – Smoulding Fire	a smoulding fire in close proximity to a sleeping area
DFS – Fire Spread to Other Property	a fire that may spread to neighbouring buildings as a result of heat transfer
DFS 7 – Vertical External Fire Spread	a fire adjacent to an external wall exposing facade materials and leading to significant facade damage and vertical fire spread
DFS 8 – Interior Surface Finishes	a fire involving surface linings or finishes
DFS 9 – Fire Service Operations	facilitating fire-fighting and rescue operations
DFS 10 – Robustness Check	the robustness of the design is tested by considering the design fire with each key safety system rendered ineffective in turn

A number of the fire scenarios can be dealt with easily without detailed analysis by selecting conventional fire protection solutions, such as defining suitable fire compartmentation, installing systems such as smoke detection or choosing non-combustible linings or claddings. Four of the scenarios are applicable for ASET versus RSET analysis including Design Fire Scenario 1, 3, 9 & 10. Each fire scenario is explained in details in the following sub-sections.

3.4.1 Design Fire Scenario 1 (DFS 1) – Challenging Fire

This scenario requires the analysis of the impact of a specified design fire located in various locations within the building. The design fire characteristics depend on purpose group and fire hazard category. It is intended to represent a credible worse case scenario that will challenge the fire protection features of the building.

Performance objective – provide a tenable environment for occupants in the event of fire while they egress to a safe place.

Design event – design fires are characterised with t-squared rate of heat release, peak rate of heat release, and fire load energy density (FLED). Design values for yields are specified for CO, CO_2 and soot/smoke. HCN production needs not be considered. The design fires are intended to represent 'free-burning' fires but they may be modified during analysis to account for building ventilation and fire suppression effects on the fire.

Performance criteria – design shall meet performance criteria for 'Occupant Tenability' and 'Structural Fire Performance' in Section 3.8.

Expected methodologies – tenability analysis.

Assumptions – active and passive fire safety systems in the building may be assumed to perform as intended by the design; a single fire source shall be utilised to evaluate the protection measures.

Applications – tenability analysis required where:

- Any room/space > 200 m^2; and
- Any room/space with occupant load >150 persons; and
- Any room > 2 m^2 (excluding toilet facilities) connected to, but not fire separated from an exitway.

In other rooms / spaces, occupants egress from the room need not be modelled, however the effect of the fire on other building occupants should still be considered.

3.4.2 Design Fire Scenario 2 (DFS 2) – Blocked Exit

The fire is considered to be located near the primary escape route or exit that prevents occupants from leaving the building by that route. Fire originating within an exitway may be the result of a deliberately lit fire or be accidental. Fire originating within an escape route in the open path will be considered to be a severe fire applicable to the particular building use as described in DFS 1. This scenario is intended to result in a second exit and addresses the concern of an escape route being blocked while sufficient number of exits and width still available. Where exits are not equally sized, the widest exit shall be considered blocked and unusable.

Performance objective – provide a viable escape route from the building for occupants in the event of fire, e.g. provide at least 2 exits of equal size.

Design event – fire blocking the widest exit in open or safe path. Fire characteristics are not required since fire is assumed to physically block the exit. (The fire is assumed to be of a size that would prevent use of the exit).

Performance criteria – by inspection since occupant tenability criteria cannot be met where fire plumes and flame block an exit.

Expected methodologies – provide alternative escape routes that are tenable or design single escape routes so that no more than 50 people are served for open paths or 150 people for vertical safe path. Analysis is not required.

Assumptions – active and passive fire safety systems in the building may be assumed to perform as intended by the design; blocked exit is deemed untenable.

Applications – this scenario applies to escape routes where:

- An open path or horizontal safe path serving more than 50 people; and
- A vertical safe path serving more than 150 people, or if the building is sprinkler protected, 250 people.

Escape routes serving less than 50 persons will be permitted to have a single exit.

3.4.3 Design Fire Scenario 3 (DFS 3) – Fire in Unoccupied Room

This scenario is intended to address the concern regarding a fire starting in a normally unoccupied room and then migrating into other space that can, potentially, hold the greatest number of occupants in the building.

Performance objective – maintain tenable conditions on escape routes until the occupants have evacuated; protect against fire spread that could compromise the retreat of firefighters.

Design event – use fire characteristics from DFS1 for the applicable occupancy.

Performance criteria – performance criteria for 'Occupant Tenability'.

Expected methodologies – include fire separations or fire suppression to confine the fire to room of origin; or include automatic detection to provide early warning of the fire in the unoccupied space; or carry out tenability analysis of escape routes if fire is able to spread into the occupied space.

Assumptions – active and passive fire safety systems in the building may be assumed to perform as intended by the design.

Applications – this scenario applies to buildings with rooms or spaces that have an occupant load of 50 or more.

3.4.4 Design Fire Scenario 4 (DFS 4) – Fire in Concealed Space

This scenario is intended to address a concern regarding a fire originating in a non fire separated concealed space that does not have either a detection system or suppression system that spreads into the room within the building that can potentially hold the greatest number of occupants. Fire spreading in concealed spaces may also compromise the ability of firefighters to assess the threat to themselves whilst undertaking rescue and fire-fighting operations.

Performance objective – maintain tenable conditions in escape routes until the occupants have evacuated; protect against fire spread that could compromise the retreat of firefighters.

Design event – Currently unable to identify a suitable quantitative description of the design event, and would expect that traditional solutions would apply, e.g. containment, detection or suppression.

Performance criteria – refer to criteria for 'Occupant Tenability Limits' and 'Firefighter Expectations'.

Expected methodologies – Provide fire separations or suppression to confine fire to concealed space or provide automatic detection for early warning.

Assumptions – active and passive fire safety systems in the building may be assumed to perform as intended by the design.

Applications – this scenario applies to buildings with rooms holding more than 50 occupants and with concealed spaces. It does not apply if the concealed space has no combustible materials and is less than 0.8 m deep.

3.4.5 Design Fire Scenario 5 (DFS 5) – Smouldering Fire

This scenario addresses the concern regarding a slow smouldering fire that causes a threat to sleeping occupants.

Performance objective – provide means of alert to sleeping occupants in the event of fire.

Expected methodologies – Provide automatic smoke detection in sleeping rooms and further analysis is not required.

Applications – this scenario applies to buildings with sleeping occupants.

3.4.6 Design Fire Scenario 6 (DFS 6) – Fire Spread to Other Property

A large fire within a building may spread to neighbouring property as a result of heat transfer (predominantly by radiation through openings in external walls). To reduce the probability of fire spread between neighbouring properties, measures to limit the radiation flux received by the neighbouring building are required. There are two parts considered for this scenario:

- Unprotected area in the external wall of the building allows neighbouring property to be subjected to radiation, so the unprotected area needs to be limited to reduce the radiation to neighbours to a safe level; and
- The external walls of the building may be subjected to radiation in the event that a fire occurs in the neighbouring property, so the external walls need to have some resistance to ignition depending on how far they are located from the boundary.

Performance objective – prevent fire spread to other property and adjacent buildings / spaces where people sleep.

Design event – Emitted Radiation flux from unprotected areas in external walls (assuming no intervention) shall be taken as:

- 88 kW/m^2 where FLED = 400 MJ/m^2
- 108 kW/m^2 where FLED = 800 MJ/m^2
- 152 kW/m^2 where FLED > 1200 MJ/m^2

In the case of a sprinkler protected building, the unprotected area is considered to be 6 m^2.

Performance criteria – external walls shall be designed to limit the radiation received on the neighbouring property to:

- No more than 30 kW/m^2 on the relevant boundary; and
- No more than 16 kW/m^2 at 1 m beyond the relevant boundary.

External walls of buildings, if located 1 m or closer to a relevant boundary, shall either be of non-combustible construction, or when subjected to a radiant flux of 30 kW/m^2 shall:

- Not ignite within 30 minutes for PG 3 & PG 4;
- Not ignite within 15 minutes for PG 1 & PG 2.

Expected methodologies – the following methodologies are acceptable:

- C/AS1 tabulated data for boundary distances; or
- Unprotected areas can be calculated using the given emitted and maximum permitted received radiation levels, boundary distances and configuration factors; or
- Fire tests of external cladding systems using the cone calorimeter apparatus or similar may be needed to demonstrate resistance to ignition to meet the above performance criteria.

Assumptions – controlling fire spread between buildings is a shared responsibility and depends both on the radiation emitted from the source building and resistance to ignition provided by the external surfaces of the receiving building; The emitted radiation levels correspond to gas temperatures reached in the standard fire resistance test after 30, 45 and 90 minutes; Flame projection from openings has not been accounted for.

Applications – this scenario applies to all buildings except those with an automatic sprinkler system with a Class A water supply as defined in NZS 4541[33].

3.4.7 Design Fire Scenario 7 (DFS 7) – Vertical External Fire Spread

A fire source adjacent to an external wall such as a fire plume emerging from a window opening or a fire source in close contact with the facade that could ignite and spread fire vertically. There are two parts to this scenario:

- External vertical fire spread via the facade materials; and
- Window fire plumes spreading fire through openings located above.

Performance objective – (1) prevent fire spread to other property and adjacent buildings / spaces where people sleep in the same building, and maintain tenable conditions on escape routes until occupants have evacuated; (2) protect against external vertical fire spread that could compromise the safety of firefighters working in or around the building.

Design event – There are two design events applicable:

- For the external vertical fire spread via the facade materials:
  1) *Radiant flux of 50 kW/m² impinging on the facade for 15 minutes for PG 2 & PG 3;*
  2) *Radiant flux of 90 kW/m² impinging on the facade for 15 minutes for PG 4.*
- For window plume projecting from opening in external wall, the characteristics are determined from design fire for DFS 1.

50 kW/m² is a representative of the flux from a window plume projecting from an opening in the facade, although higher fluxes are certainly possible. Current large-scale facade fire tests expose the facade to heat fluxes in the range 50-90 kW/m². C/AS1 allows fire properties of cladding materials to be evaluated at small scale exposing the material to 50 kW/m². Acceptance criteria (say not more than 100 kW/m² peak HRR) is based on achieving a low probability of occurrence of accelerating flame spread over the surface of a combustible cladding. Small-scale testing is not suitable for all materials.

Performance criteria – (1) prevent facade cladding materials from contributing to significant flame spread propagation beyond the area initially exposed. Some damage to the area initially exposed will be expected. This may be achieved by limiting the maximum HRR from a cladding material when exposed to the design event to no more than 100 kW/m^2 or by limiting the extent of the vertical flame spread distance on the facade to no more than 3.5 m above the fire source. This accepts fire spread via the facade materials may occur to the floor immediately above but not two floors above. (2) In unsprinklered buildings, it is required to prevent fire spread from projecting window plumes to unprotected areas on upper floors where they are within 1.5 m vertically of a window plume fire source.

Expected methodologies – the following methodologies are acceptable:

- Follow existing C/AS1 and use:
  1) *Large or medium-scale 'facade type' fire tests (e.g. NFPA 285, ISO 13785, VCT); or*
  2) *Small-scale testing using ISO 5660 or AS/NZS 3837 (cone calorimeter) for homogeneous materials. Limit the maximum heat release rate from a cladding material to 100 kW/m^2 when exposed to the design event to ensure flame spread over its surface is unlikely.*
- Use non-combustible materials; or
- Validated flame spread models could be used for some materials; or
- Construction features such as 'aprons' and / or 'spandrels' or 'sprinklers' can be used to prevent window fire plumes spreading vertically through higher openings. Window plume characteristics / geometry may be derived from DFS 1 design fires.

Applications – this scenario applies to:

- Buildings where upper floors contain sleeping occupancies or 'other property'; and
- Buildings of height > 10 m.

This scenario does not apply to PG 1 buildings.

3.4.8 Design Fire Scenario 8 (DFS 8) – Interior Surface Finishes

This scenario concerns a flaming source located in a wall-corner junction that ignites room surface lining materials and which then subsequently leads to untenable conditions on an escape route.

Performance objective – maintain tenable conditions on escape routes until the occupants have evacuated; protect against rapid fire spread that could compromise the retreat of fire-fighters.

Design event – Fire source of output 100 kW in contact with a wall-corner element for 10 minutes followed by 300 kW for 10 minutes in accordance with ISO 9705.

Performance criteria – performance criteria for lining materials depend on their location in the building and the occupancy type or building Performance Group. The effect of any fire suppression or smoke management system on the fire development shall be ignored except that the smoke production rate criteria need not apply for sprinkler protected buildings.

1. For wall / ceiling materials in exit ways; and sleeping areas where occupants are detained or under care; and all occupied spaces in PG 4 buildings:

Time to flashover shall be not less than 20 minutes under ISO 9705 test condition, and average smoke production rate over the period 0 – 20 minutes shall be no greater than 5 m^2/s;

2. For wall / ceiling materials in assembly / crowd use spaces; and sleeping areas where occupants are not familiar with surroundings; and floor surfaces in vertical safe paths:

Time to flashover shall be not less than 10 minutes under ISO 9705 test condition, and average smoke production rate over the period 0 – 10 minutes shall be no greater than 5 m^2/s;

3. For wall / ceiling materials in all other locations including within household units and detached dwellings:

Time to flashover shall be not less than 2 minutes;

4. Floor surface in horizontal safe paths, assembly / crowd purpose groups and sleeping areas where occupants are detained or under care; and all occupied spaces in PG 4 buildings shall meet floor radiant panel criteria.

Expected methodologies – the following methodologies are acceptable:

- ISO 9705 room corner fire test or ISO 5660 cone calorimeter test at 50 kW/m² (used with a correlation to a ISO 9705 full scale result); or
- Use non-combustible materials to AS 1530.1 or ISO 1182.

This methodology in DFS 8 has been the subject of significant research in Europe and Australia, and more recently here in New Zealand. The current methodology applied in the Building Code of Australia can be adopted as a model. This uses the ISO 9705 method as a reference scenario. AS/NZS 3837 (cone calorimeter or ISO 5660) results have been correlated to ISO 9705 and can also be used for most materials. Surface linings are exposed to 100 kW for 10 minutes and then 300 kW for a further 10 minutes and the time to reach flashover (~1MW in 3.6 x 2.4 x 2.4 m room) is determined. Materials are classified from Group 1 (best) to Group 4 (worst) based on their measured time to flashover in the fire test.

- Group 1 materials – these include non-combustible mateirals or materials with limited combustibility. e.g. plasterboard and similar materials (low hazard) [no flashover in 20 minutes];
- Group 2 materials – these typically include many fire retardant treated timbers etc. [no flashover in 10 minutes];
- Group 3 materials – these typically include ordinary timber products and similar [no flashover in 2 minutes];
- Group 4 materials – these typically include exposed polyurethane foams or similar (these are hazardous when installed as room linings and are not acceptable in occupied spaces) [flashover within 2 minutes].

Assumptions – The main fuel loads in exitways are attributed to the materials used to line the walls, ceiling and floor surfaces, while in other spaces the fuel loads from the surface lining are usually secondary to the room contents. The design event is unaffected by sprinklers.

Applications – this scenario applies to all buildings except that the smoke production rate criteria need not apply for sprinkler protected buildings. Criteria need not be applied to small areas of product within a firecell less than 5 m^2 or 5 % of floor area whichever is greater.

3.4.9 Design Fire Scenario 9 (DFS 9) – Fire Service Operations

It goes without saying that a building on fire is a dangerous place, and the first duty of the occupants of such a building is to leave. Firefighters are authorized by law to enter buildings on fire for the purposes of firefighting and rescue operations. Though the officer in charge will ultimately take the final decision on whether or not to commit firefighting crews to a building that is on fire, one of the principles of the Building Act 2004[12] is that firefighters have reasonable expectations that they should not suffer illness and injury whilst undertaking firefighting and rescue operations. Mitigation of risk on the fire ground on the part of the officer requires the ability to predict both fire and building behavior. That compromises this ability is the occurrence of events that are sudden, unexpected or disproportionate to the change that caused them. It is the broad predictability of the building behavior and the fire environment that is encapsulated in the concept of 'reasonable expectations' of firefighters to be safe.

Performance objective – In order that the officer in charge may make a risk-informed judgement about how to tackle firefighting and rescue operations:

- Information must be available to the crew on arrival to enable them to rapidly size-up the situation; and
- Access to all floors of the building must provide firefighter protection; and
- Firefighting water must be available in the vicinity of the fire.

Design event – Firefighter tenability must be established for:

- Large buildings with floor area > 1500 m^2 and FLED > 1500 MJ/m^2 where fire growth rate is very rapid; or
- Unsprinklered buildings where the distance from the safe path access to any point on a floor exceeds 75m.

The firefighting design fire is 50 MW, unless the fire is sprinkler, ventilation or fuel limited at some lower value by the time the fire service arrives.

Performance criteria – the following criteria apply:

- Information is available in a conventional manner to facilitate on-site assessment of conditions; and
- Access is available for firefighters to positions from which the fire may be fought and from which safe retreat may be made (refer to criteria for 'Firefighter Tenability'); and
- Firefighting water is available in a conventional manner so that it can be used in the vicinity of the fire. Water is to be available from either a pumping appliance parked close to the building such that any point within the building may be reached within 75 m, or an internal hydrant system.

Expected methodologies – the following methodologies are acceptable to meet the above three performance criteria:

- Features that facilitate rapid size-up of the situation
  1) *Hazardous substance signage*
  2) *Fire detection system*
  3) *Panel location and information*
  4) *Fire service alarm connection*
  5) *Fire control room*
  6) *Firefighter control of building fire safety systems*
  7) *Limitation of fire size by sprinklers or firecell size*
- Features that facilitate safe access for rescue and firefighting
  1) *Firefighter access around building*
  2) *Sprinklers in buildings higher than fire service ladder appliances*
  3) *No conflict with security systems*
  4) *Access through tall buildings via*
     - *Protected from structural collapse*
     - *Protected from fire outbreak in the access*
     - *Lifts with firefighter controls*
  5) *Tenable routes through large open spaces by providing sprinklers and /or effective venting*
- Features that facilitate adequate firefighting water
  1) *External hydrants plus fire appliance access to building*
  2) *Internal risers, hydrants and hosereels*
  3) *Sprinklers*

Assumptions – active and passive fire safety systems in the building may be assumed to perform as intended by the design. Meeting other objectives in the Building Code cannot rely on firefighter intervention.

Applications – all buildings except that houses are only required to provide features to facilitate adequate firefighting water.

3.4.10 Design Fire Scenario 10 (DFS 10) – Robustness Check

This scenario is intended to do a robustness check for the ASET calculations from DSF 1. Ideally, a comprehensive quantitative probabilistic risk assessment would be used to assess the safety of a design. However, the risk assessment tools and supporting data are not currently developed to a level where the Department of Building and Housing (DBH) is comfortable with the inclusion within the proposed C/VM2. Therefore, it is currently required a deterministic ASET versus RSET approach.

Performance objective – provide a tenable environment for occupants in the event of fire while they escape to a safe place.

Design event – same as DFS 1.

Performance criteria – design shall meet performance criteria for 'Occupant Tenability' except that only FED CO applies. FED Thermal and Visibility need not be assessed.

Expected methodologies – tenability analysis required by considering the design fire with each key fire safety system rendered ineffective in turn.

Applications – in general, fire safety systems may be assumed to operate as designed provided they are manufactured and installed in accordance with recognized standards. However, in the following situations, additional fire safety systems are required to provide redundancy and robustness to the fire safety design.

- Failure of a key system would expose more than 150 occupants to untenable conditions; or
- Failure of a key system would expose more than 6 occupants in sleeping care occupancy firecell to untenable conditions.

Key fire safety systems include:

- Smoke management systems; and
- Fire and / or smoke doors or similar.

3.5 Design Fires

The design fires nominated in the proposed C/VM2 are characterised using one or more of the following parameters, which are specified for both pre- and post-flashover fires as appropriate. For pre-flashover fires, only the initial conditions are specified. The designer may determine at what time the HRR becomes ventilation-limited or reaches flashover.

- Fire growth rate
- peak heat release rate
- Fire load energy density
- Species production (CO, CO_2, water, soot)
- Heat flux
- Time

3.5.1 DFS 1 Design Fires

3.5.1.1 Pre-flashover

For all buildings except those in Table 3.5, the fire is assumed to grow as a fast t^2 fire up to flashover and is then limited by the available ventilation assuming all windows are broken out. For sprinkler protected buildings the fire is assumed to be controlled, e.g. constant heat release rate after the sprinkler activates based on the RTI and activation temperature. The parameters for pre-flashover t^2 fire are summarised in Table 3.6.

Table 3.5: Design fire parameters for carparks & rack storage groups

Building Use	Fire Growth Rate (kW)	Species
Carparks	$0.0117t^2$	$Y_{soot} = 0.07$ $Y_{CO} = 0.04$ $\Delta H_C = 20$ MJ/kg
Rack Storage Group 1 (Polystyrene chip in single wall cardboard cartons)	$0.0088t^3$ H	$Y_{soot} = 0.07$ $Y_{CO} = 0.04$ $\Delta H_C = 20$ MJ/kg
Rack Storage Group 2 (FMRC Standard Plastic commodity, upholstery cushions)	$0.0025\ t^3$ H	$Y_{soot} = 0.07$ $Y_{CO} = 0.04$ $\Delta H_C = 17$ MJ/kg
Rack Storage Group 3 (FMRC Class II Double triwall cardboard cartons)	$0.00068t^3$ H	$Y_{soot} = 0.07$ $Y_{CO} = 0.04$ $\Delta H_C = 15$ MJ/kg
Others	Fast t^2	$Y_{soot} = 0.07$ $Y_{CO} = 0.04$ $\Delta H_C = 20$ MJ/kg

Key: H (m) – height of rack storage

Table 3.6: Design fire parameters for fast t^2 fire

Parameters	Values
Fire growth rate	$Q = 0.047t^2$
Pre-flashover species yield for soot	$Y_{soot} = 0.07$
Pre-flashover species yield for CO	$Y_{CO} = 0.04$
Net heat of combustion	$\Delta H_C = 20$ MJ/kg
Radiative fraction	0.35
Peak HRR (free burning)	20 MW
Peak HRR (free burning) for firefighting design fire	50 MW

3.5.1.2 Post-flashover

Post-flashover fire has the following characteristics:

- It is assumed to occur when the average upper layer temperature reaches 500ºC;
- For uncontrolled fires, the burning is assumed to be controlled by the ventilation limit or the peak heat release rate whichever is greater;
- Flashover should be modelled as a linear transition from the growth phase to fully developed phase over a 15 s period. It is expected that modelling the fire into post-flashover is an iterative process. The basic steps are outlined below.

1) *Determine initial pre-flashover fire growth rate, typically* $q=0.047t^2$
2) *Run fire model until upper layer reaches* 500^oC *and record the time to reach* 500^oC.
3) *Calculate the ventilation controlled heat release rate using* $\dot{q}_{VL} = 1500 A_o \sqrt{h_o}$.

   where, $\dot{q}_{VL}$ *ventilation limited heat release rate (kW)*
   A_o *sum of the areas of all openings (m)*
   h_o *average height for all openings (m)*
4) *Amend the design fire heat release rate to increase to the ventilation limit value 15 seconds after the upper layer temperature reaches* 500^oC.
5) *Allow fire to burn until all the fuel is exhausted based on the expected FLED. Design FLEDs are provided in Table 3.7 for activities within buildings.*

- Post-flashover species yield for soot (Y_{soot} = 0.14 kg/kg-fuel);
- Post-flashover species yield for carbon monoxide (Y_{CO} = 0.40 kg/kg-fuel).
- For sprinkler protected buildings the fire is assumed to be controlled, i.e. constant heat release rate, after the sprinkler activates based on RTI and activation temperature. It is expected that flashover will not occur in a sprinkler protected controlled fire.

Table 3.7: Design FLEDs for post-flashover design fires

Design FLED (MJ/m^2)	**Activities**	**Examples**
400	Display or other large open spaces	Art galleries, auditoria, bowling alleys, churches, clubs, community halls, court rooms, day care centers, gymnasia, indoor swimming pools
	Seating areas without upholstered furniture	School classrooms, lecture halls, museums, eating places without cooking facilities
	All spaces where occupants sleep	Household units, motels, hotels, hospitals, residential care institutions
	Working spaces and where storage of low fire hazard materials are stored.	Wineries, meat processing, manufacturing plants
	Support activities of low fire hazard	Car parks, locker rooms, toilets and amenities, service rooms.
800	Spaces for business	Banks, personal or professional services, police stations, (without detention).
	Seating areas with upholstered furniture	Nightclubs, restaurants and eating places, early childhood centers, cinemas, theatres, libraries
	Spaces for display of goods for sale (retail, non bulk)	Exhibition halls, shops and other retail (not bulk)
1200	Spaces for working or storage with moderate fire hazard	-Manufacturing and processing moderate fire load -Storage up to 3m high other than foamed plastics
	Workshops and support activities of moderate fire hazard	maintenance workshops, plant and boiler rooms

Design FLED (MJ/m^2)	Activities	Examples
800/m height with a minimum of 2400	Spaces for working or storage high fire hazard.	-Chemical manufacturing and processing, feed mills, flour mills -Storage over 3m high of combustible materials, including climate controlled storage.
	Spaces for display and sale of goods (bulk retail)	Bulk retail (over 3m high)

3.5.2 Structural Design Fire

Design fire characteristics (for DFS 1) include parameters for the fire load energy density, fire growth rate and heat of combustion, allowing a post-flashover structural design fire to be defined. The 'structural design fire' shall be based on complete burnout of the firecell with no intervention.

The engineer shall either:

- Construct a Heat Release Rate versus time structural design fire using these parameters and, taking into account ventilation conditions, use a fire model or energy conservation equations to determine suitable thermal boundary conditions (time / temperature / heat flux) for input to a structural calculation model; or
- Use a parametric or time-equivalent formula to calculate the thermal boundary conditions (time / temperature) for a structural model or the fire resistance rating directly.

The recommended approach to use is the 'equivalent fire severity' method described in *Structural Design for Fire Safety*[34]. This allows the equivalent time of exposure to the standard fire test to be estimated based on the compartment properties, fire load energy density and available ventilation given complete burnout of the firecell with no intervention.

The effects of sprinkler intervention on the structural design fire may be included by reducing the design fuel load energy density by 50 % except in the case of primary elements whose failure could cause disproportionate collapse where there should be no reduction (e.g. isolated columns in a multi-storey building leading to sudden and complete failure). However, in no case, should an equivalent structural severity of less than 30 minutes be used.

3.6 Fire Modelling Rules

For DFS 1, designers shall demonstrate that the occupants have sufficient time to evacuate the building before being overcome by the effects of fire. In engineering terms, the Available Safe Egress Time (ASET) shall be greater than the Required Safe Egress Time (RSET). The ASET shall be calculated using a fire model chosen by the fire engineer using the specified design fire. In most cases there will be a number of locations of the fire that could produce the lowest ASET. The fire engineer will have to check a number of rooms to determine the limiting case. The following general rules apply for fire modelling:

- There must be automatic warning systems to alert the occupants of a fire;
- Fire/Smoke doors with self closers are assumed closed unless being used by occupants. During egress, doors are assumed to be open for 3 seconds per occupant or for the duration of queuing whichever is the lesser;
- Doors without self-closers are assumed to be open during the analysis;
- Doors being used for egress are assumed to be half-width for ventilation flow calculation;
- Smoke control doors are assumed to have zero leakage area, except for a 10 mm gap at the sill;
- Unrated walls are assumed to have leakage areas that are proportional to the surface area of the walls. Leakage area is equal to the wall area multiplied by 0.001 m^2/m^2. Where zone modelling (e.g. BRANZFIRE or CFAST) is employed, leakage should be modelled as a tall narrow slot from floor to ceiling with the width of the vent determined by the calculated area. Where CFD modelling (E.g. FDS) is employed, leakage should be modeled either as a vertical slot as in zone modelling or as two vents one at floor and one at ceiling level to fit within the computational grid. Fire rated construction is considered to have no leakage;
- Fire rated doors that are not smoke control doors are assumed to have 10mm gap over the height of the door (nominally a 3mm gap on four sides);
- Windows are assumed to break at either 500°C or when the fire becomes limited by ventilation and the heat release rate reduces whichever occurs sooner;
- The fire shall be located away from walls and corners. The base of the fire shall be located at 0.4 m above floor level.

3.7 Movement of People

Evacuation time can be complex and difficult to calculate precisely. This section simply describes the minimum level of analysis expected as part of the proposed C/VM2. Designers are expected to have a detailed understanding of human behavior and evacuations modelling appropriate for fire engineering analysis. There are several references that users of this framework are expected to experience with, including:

- ‘Employing the Hydraulic Model in Assessing Emergency Movement’ by Gwynne S M V & Rosenbaum E R[35];
- ‘Evacuation Time’ by Proulx G[31];
- ‘Behavioral Response to Fire and Smoke’ by Bryan J L[36];
- ‘Engineering Guide to Human Behavior in Fire’ by SFPE[37];
- ‘The Application of Fire Safety Engineering Principles to Fire Safety Design of Buildings – Part 6: Human Factors: Life Safety Strategies – Occupant Evacuation, Behaviour and Conditions’ by BSI[38].

The Required Safe Egress Time (RSET) is the calculated time between ignition of a fire and the time at which all occupants can reach an area of safety[31]. The RSET consists of several components including:

- Detection time: time between fire ignition and the first detection of fire by a device or an individual. It is normally calculated using fire modelling;
- Alarm time: time between detection of the fire and the time at which an alarm signal is activated. This time interval is relatively short and has been counted into the pre-movement time in the proposed C/VM2;
- Pre-movement time: interval between the time at which the alarm signal is given and the time at which evacuation starts;
- Movement time: the time needed, once evacuation starts toward an exit, for all occupants to reach a place of (relative) safety. It may include the travel time walking toward an exit and the flow time when queuing occurs at the doorway.

Hence, the total RSET will be the sum of detection time, pre-movement time and movement time in Equation (3.1). When calculating the movement time from the room of origin, the occupants are assumed to be evenly distributed in the space, thus the egress time is either governed by the queuing time or the travel time to the exit, whichever is larger.

$$RSET = t_d + t_{pre} + (t_{travel} + t_{flow}) \tag{3.1}$$

where t_d (s) – Detection time
t_{pre} (s) – Pre-movement time (including alarm time)
t_{travel} (s) – Time to moving toward an exit
t_{flow}(s) – Time for a group of people to pass a point

3.7.1 Occupant Numbers

The movement time is a function of occupant characteristics, e.g. number of occupants and walking speed etc, and available means of egress. Using the proposed C/VM2, the occupant numbers shall be determined by the occupant density (using Table 2.2 of C/AS1 as shown in APPENDIX B) multiplying the floor area. Those occupant densities used in the case studies are listed in Table 3.8. Spaces for intermittent activities are normally not assessed for occupant load unless people are specifically employed to perform the functions for which the spaces are provided.

Table 3.8: Occupant density used in the case studies

Activity	Occupant Density (Users/m^2)
Crowd Activities	
Bar standing area	2.0
Dance floors	1.7
Dining, beverage and cafeteria spaces	0.8
Stages for theatrical performances	1.3
Shop spaces and pedestrian circulation areas including malls and arcades	0.3
Reading or writing rooms and lounges	0.5
Classrooms	0.5
Sleeping Activities	the number of beds
Working Business and Storage Activities	
Offices and staff rooms	0.1
Kitchen	0.1
Warehouse storage	0.03
Reception area	0.1
Commercial laboratories	0.1
Computer rooms (not used as classrooms for training)	0.04
Intermittent Activities	
Boiler rooms, plant rooms, service units and maintenance workshops	0.03
Parking buildings	0.02
Storage	0.02
Toilets, exit ways, corridors etc.	0

3.7.2 Detection Time

The detection time shall be determined from the deterministic fire modelling conducted to DFS 1 by the fire engineer. It is expected that the model used to calculate the detection time should use an appropriate fire model for this analysis that incorporates a ceiling jet algorithm which includes the upper layer or a CFD code that solves for the velocity and temperature directly. For this analysis, the designer shall use the values given in Table 3.9 for the detector. Specific data from detector manufacturers may be used in lieu provided justification and evidence is included with the design.

Table 3.9: Detector criteria for modelling

Devices	Properties
Residential sprinklers (3 mm bulb)	RTI = 36 C = 0.4 $T_{act} = 68^oC$ Radial distance = 2.8 m Depth below ceiling = 20 mm
Standard response (5 mm bulb)	RTI = 95 C = 0.4 $T_{act} = 68^oC$ Radial distance = 2.8 m Depth below ceiling = 20 mm
Heat detectors	RTI = 30 $T_{act} = 57^oC$ Radial distance = 4.2 m Depth below ceiling = 20 mm
Smoke detectors	Optical Density at alarm = 0.097 (1/m) Characteristic length = 15 m Radial distance = 7 m Distance below ceiling = 0.025 m

3.7.3 Pre-movement Time

One of the most important factors comprising evacuation analysis is the pre-movement time, which includes the time spent by occupants to response to a fire alarm and investigate the fire cues until evacuation commences. The pre-movement time can vary largely depending on the nature and state of occupants, such as alertness, familiarity, physical and mental conditions etc.

The proposed C/VM2 specifies the pre-movement time (including alarm time) to be used in the calculation of evacuation time shown in Table 3.10. Compared with the literature, the recommended values here are considered to be shorter than expected. This is due to the existing evacuation regulations which require most commercial buildings open to public to have an approved evacuation scheme. As a result, there is a widespread culture of evacuating a building when the fire alarm sounds.

It is assumed that occupants in the firecell of origin are aware of the fire much sooner than occupants in other firecells and will take action sooner than those remote from the fire. Occupants involving in focused activities such as cinemas, theatres, or stadiums, it is expected that a fire within the area would be obvious to the occupants and they would start to evacuate when the fire reaches 500 kW.

Table 3.10: Pre-movement time specified in the framework

Description of Building Use	Pre-movement Time (s)
Buildings where the occupants are considered awake alert and familiar with the building. e.g. offices, warehouse not open to the public, etc	
Fire Cell of Origin	30
Remote from the Fire Cell of Origin	60
Buildings where the occupants are considered awake, alert and unfamiliar with the building. e.g. retail shops, exhibition space, restaurants	
Fire Cell of Origin (Standard Alarm Signal)	60
Remote from the Fire Cell of Origin (Standard Alarm Signal)	120
Fire Cell of Origin (Voice Alarm Signal)	30
Remote from the Fire Cell of Origin (Voice Alarm Signal)	60
Buildings where the occupants are considered sleeping and familiar with the building. e.g. sleeping residential	
Fire Cell of Origin (Standard Alarm Signal)	60
Remote from the Fire Cell of Origin (Standard Alarm Signal)	300
Buildings where the occupants are considered sleeping and unfamiliar with the building. e.g. sleeping accommodation	
Fire Cell of Origin	60
Remote from the Fire Cell of Origin (Standard Alarm Signal)	600
Remote from the Fire Cell of Origin (Voice Alarm Signal)	300
Buildings where the occupants are considered awake and under the care of trained staff and unfamiliar with the building. e.g. day care, dental office, clinic	
Fire Cell of Origin (independent of alarm signal)	60
Remote from the Fire Cell of Origin (independent of alarm signal)	120
Buildings where the occupants are considered to be asleep, under the care of trained staff. e.g. hospitals and rest homes. (PG3 & PG4)	
Room of Origin (independent of alarm signal)	180
Fire Cell of Origin	300
Remote from the Fire Cell of Origin (independent of alarm signal)	1800
Spaces which have only focused activities. e.g. cinemas, theatres, stadiums, etc	
Evacuation starts when fire reaches 500 kW or 60 s after detection whichever is first	

3.7.4 Travel Time

The travel time is calculated based on the estimated walking speed. Although research has shown that walking speed varies with age and gender, a typical unimpeded walking speed of 1.2 m/s is considered a reasonable upper limit for adults. As the occupant density increases above 0.54 persons/m^2, occupants slow down and cease to move when the density exceeds 3.8 persons/m^2.

The walking speed, as a function of density and travel inclination, can be calculated as Equation (3.2). The value of constant *k* varies depending on the travel inclination, and stair riser and tread size shown in Table 3.11. Then, the travel time is simply the travel distance divided by the travel speed. The maximum travel distance shall be taken as the sum of the length and width of the room.

$$S = k - \alpha k D \tag{3.2}$$

Where S (m/s) – Walking speed
D (persons/m^2) – Occupants density
k – Constant, as shown in Table 3.11
$\alpha = 0.266$

Table 3.11: k value for calculating travel speed

Exit Route Elements		*k*	Flow speed (m/s)
Horizontal travel			
Corridors, aisle, ramp, doorway		1.4	1.19
Vertical travel			
Riser (mm)	Tread (mm)		
191	254	1.00	0.85
178	279	1.08	0.95
165	305	1.16	1.00
165	330	1.23	1.05

3.7.5 Flow Time

Flow time is the dominant component for crowd movement which is defined as time for a specified number of people passing some reference point. It is a function of occupant density, walking speed and the available width of egress route. The flow rate of people passing a particular point can be calculated using Equation (3.3):

$$F_c = (1 - \alpha D) k D W_e \tag{3.3}$$

Where F_c (persons/s) – Calculated flow rate
W_e (m) – Effective width of component being traversed

The effective width is the usable width of the component which is the measured clear width of that portion of an exit route minus the sum of the boundary layers. The thickness of the boundary layer is given in Table 3.12. For doorway flows, the maximum flow rate is limited to 50 persons/min for each door leaf that is not mechanically held open. This corresponds to a door of 0.95 m wide with a boundary layer of 0.15 m and a total effective width of 0.65 m.

Table 3.12: Boundary layer width for calculating the effective width of an exit route element

Exit Route Element	Boundary Layer (cm)
Stairways – walls or side tread	15
Railing or handrail	9
Theatre chairs, stadium benches	0
Corridor, ramp walls	20
Obstacles	10
Wide concourse, passageway	46
Door, archways	15

3.8 Performance Criteria

We have known that the Available Safe Egress time (ASET) is the interval from time of ignition to the time when the first tenability criterion is reached in a specified room of interest. The ASET needs to exceed RSET to ensure the safety of occupants. Hence, it is vital to specify appropriate tenability criteria for ASET calculations. The proposed C/VM2 specifies criteria for 'Occupant Tenability' and 'Firefighter Tenability' that designers are obligated to use.

3.8.1 Criteria for Occupant Tenability

Two performance criteria are suggested for occupant tenability summarised in Table 3.13. The simple criteria are used when the smoke layer is not expected to impact the occupants. It is not suitable for spaces with low ceilings or where a distinct layer interface cannot be determined. The detailed criteria shall be used whenever the occupants are expected to have to egress through the smoke. FEDs and Visibility shall be determined at a height of 2.0 m above the floor level using upper / lower layer properties as applicable, or else can be based on upper layer properties alone.

For unsprinklered buildings where occupants may expose to smoke, all three criteria must be achieved. However, exceptions are applied for sprinklered buildings that only FED for CO shall be achieved. Firstly, this due to the rigorous inspection and maintenance regime for sprinkler system in New Zealand, which helps to ensure that the system will function as designed when required. In addition the current level of modelling does not adequately take into account the positive effect sprinklers can have, so the relaxation of the performance criteria is necessary to promote the use of sprinklers. Secondly, the performance criteria are not assessed within the household unit of origin.

Table 3.13: Performance criteria for occupant tenability

Simple Criteria	
Smoke layer height	≥ 2.5 m
Upper layer temperature	≤ 200°C
Detailed Criteria	
Fractional Effective Dose (FED) for CO	≤ 0.3
Fractional Effective Dose (FED) for radiant and convective heat (not applicable for sprinklered building)	≤ 0.3
Visibility (not applicable for sprinklered building)	≥ 5 m for rooms/spaces ≤ 100 m^2 ≥ 10 m for rooms/spaces >100 m^2

3.8.2 Criteria for Firefighter Tenability

Where firefighter tenability is applicable under DFS 9, the following criteria are applied as specified in Table 3.14. For firefighter to do their jobs safely, they need safe access to the fire floor and sufficient water for firefighting. Fire resistance of the structure or separating construction is required to meet the structural stability criteria. Where firefighters have to search large spaces with the potential for rapid fire growth, or where the distance from safe path access to any point on a floor is in excess of 75 m, criteria for smoke & heat are applied.

Table 3.14: Performance criteria for firefighter tenability

Structural Stability	
Buildings with escape height > 10 m	▪ Provide firefighters with safe paths allowing them access to all floors not directly accessible from street level within the building designed to resist burnout; and ▪ Protect firefighters and others at ground level and within the building by designing the load carrying structure and floor systems to resist collapse.
Buildings with escape height < 10 m	Provide firefighters with safe paths allowing them access to all floors not directly accessible from street level within the building for a period of 60 minutes from ignition, or to resist burnout whichever is less
All floors (incl. intermediate floors)	Required to resist fire from below for a period of no less than 30 minutes from ignition
Smoke & Heat	
No direct thermal radiation (e.g. <1kW/m^2)	▪ Maximum ambient temperature ≤ 100°C; and ▪ Maximum time of exposure ≤ 25 minutes.
With direct thermal radiation	▪ Maximum ambient temperature ≤ 120°C; and ▪ Maximum radiation ≤ 3kW/m^2; and ▪ Maximum time of exposure ≤ 10 minutes.

CHAPTER 4 METHODOLOGY

4.1 Analysis Procedure

As the proposed C/VM2 is intended to deliver a similar level of safety as C/AS1, it is of interest to compare C/AS1 compliant buildings with the performance criteria prescribed in the proposed C/VM2. Hence, each case study building was designed in accordance with the minimum requirements in C/AS1, followed by the C/VM2 analysis, that the design is expected to meet all performance criteria against each of the ten fire scenarios. If a C/AS1 compliant building does not meet the C/VM2 criteria, the proposed C/VM2 may provide higher level of safety than that of C/AS1 for similar type of buildings. The analysis procedure for each case study building is illustrated in Figure 4.1.

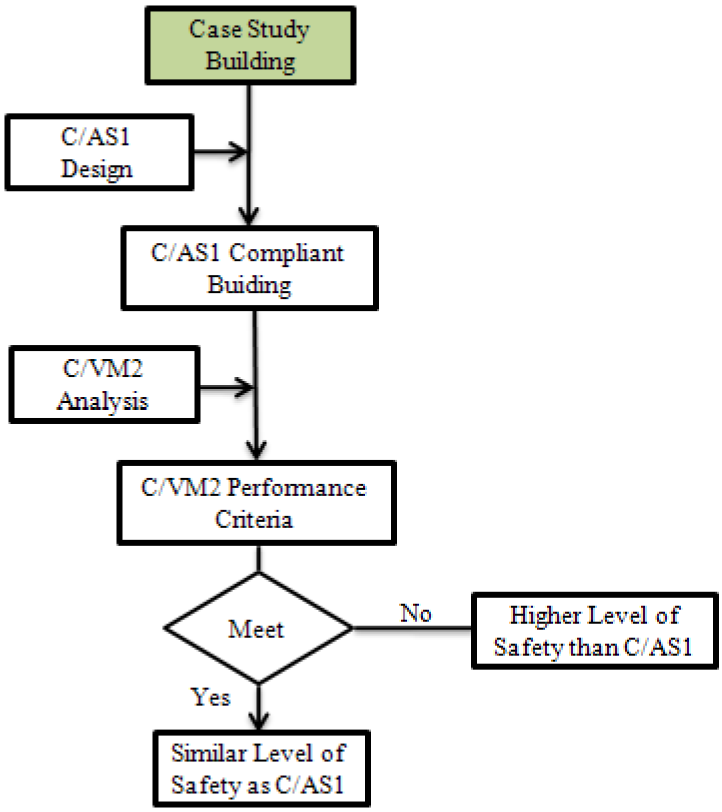


Figure 4.1: Flow chart showing the analysis procedure for each case study building

Under C/VM2 analysis, each building was analysed against the performance criteria for each design fire scenario. Where tenability analysis applies, ASET was calculated using fire modelling including BRANZFIRE and Computational Fluid Dynamics (CFD) model. Hydraulic model was employed to calculate RSET whilst Simulex was also used for the nightclub building due to its complicated egress system compared to the other three buildings. Design Fire Scenario 1 involves the most tenability analysis which is required in several fire locations to determine the limiting case.

4.2 Available Safe Egress Time (ASET)

The most common types of fire models are zone model and field model, each of which has its pros and cons. Where tenability analysis applies, the dominant fire model used for ASET calculation was BRANZFIRE zone modelling Version 2010.5. The field model, Fire Dynamic Simulator (FDS) Version 5.5.1, was used to further extend the research to evaluate the differences between the two fire models. For all case study buildings, the ASET was calculated using 'detailed criteria' as per proposed C/VM2 that the design shall meet all the tenability criteria of FED CO, FED Thermal and Visibility unless the building is sprinklered that only FED CO applies.

4.2.1 BRANZFIRE

BRANZFIRE is a multi-compartment two-zone fire model which is widely used for fire simulation in New Zealand. It has the benefits of free to use, easy to set up and providing results quickly compared to CFD models. Similar to other two-zone fire models, BRANZFIRE represents the fire environment within an enclosure as two homogenous layers, comprising an upper smoke layer and a lower ambient layer. It can be used to predict the impact of the fire in both upper and lower layers including temperature, species concentration, vent flow, layer interface height, fractional effective dose (FED), visibility and sprinkler / detector actuation. BRANZFIRE is based on a set of differential equations that predict state variables using enthalpy and mass flux over small time steps. These equations are derived from the conservation of energy and mass, and the ideal gas law. For further details regarding to the BRANZFIRE model, readers shall refer to its user's guide[39] and technical reference guide[40] which are free to download at www.branzfire.com/frst/documentation/.

It shall be noted that there are certain limitations on use of BRANZFIRE. Similar to other zone models, transport time details are lost in zone models[41]. It does not account for the time required to transport hot gases vertically or horizontally. It may not be suitable for rooms with a large length-to-width ratio or rooms where the horizontal length to vertical length ratio is very large or very small[42]. Meanwhile, the fire must be large enough so that there is sufficient enthalpy in the plume to drive the fire gases to the ceiling.

Wade C A (2008) has conducted several verifications comparing BRANZFIRE predictions with FDS and experimental data[43]. Generally, BRANZFIRE provides good predictions of average hot layer temperature and layer height, when compared with FDS, for single room models with floor areas up to about 1200 m^2. It is not recommended for larger enclosures up to 5000 m^2 or compartments higher than 12 m[44]. For these cases, the model user should consider the use of a CFD model, or sensitivity analysis should be conducted subdividing the enclosure into virtual rooms as well as a single zone simulation.

It shall be noted that there are three locations in BRANZFIRE where users can specify inputs for smoke production. Using the proposed C/VM2, productions for CO and soot shall be set as 'Manual input' with corresponding values for pre / post flashover fire as shown in Figure 4.2. In this case, any inputs of CO / Soot production when defining the fire objects (shown in Figure 4.3) will not affect the results. Meanwhile, in the screen of 'Combustion Parameter' shown in Figure 4.4, the fuel type shall be set as 'user defined' to input the radiant loss fraction of 0.35 manually. The molecular composition shall be set according to the type of fuel. However, it only has a small influence on the results as it is used to determine the production of HCN and H_2O, while HCN is not considered in the proposed C/VM2, and H_2O has only small influence on the radiation exchange through the gas layers.

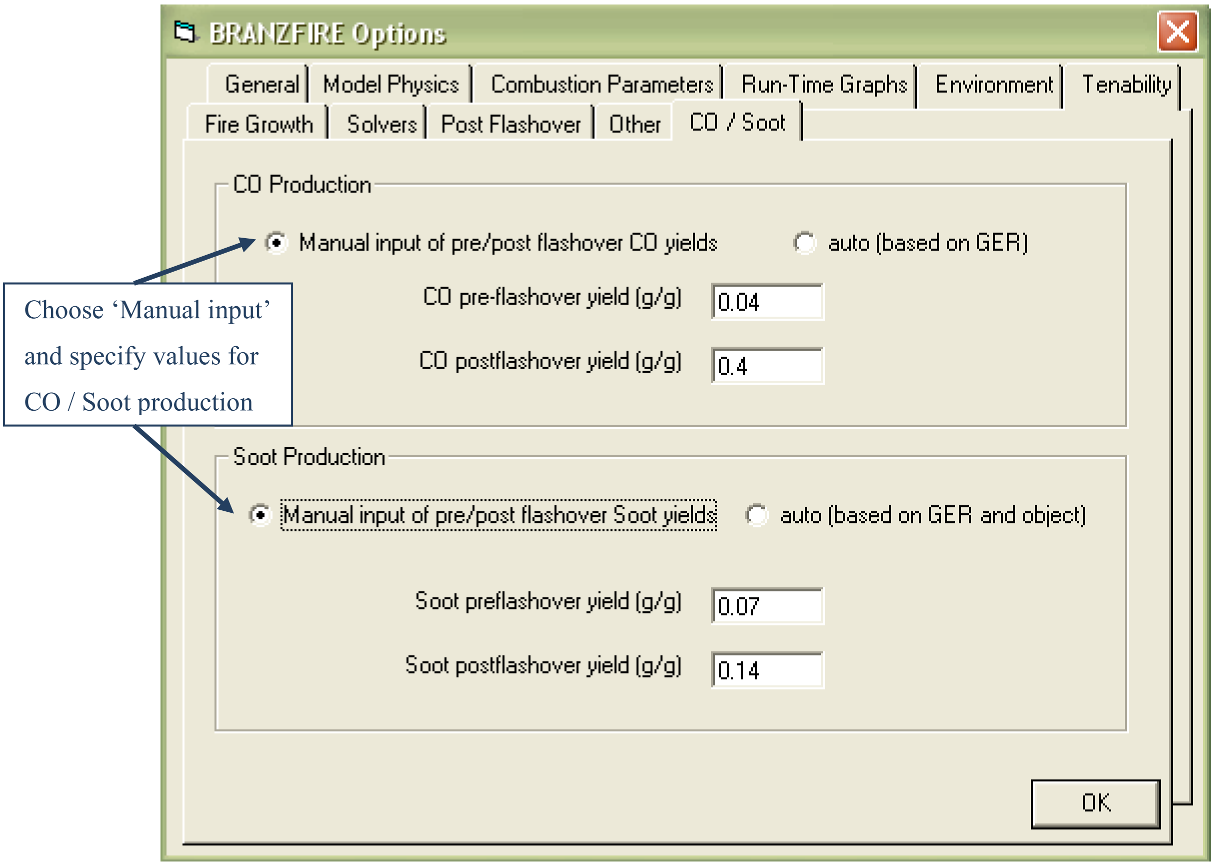


Figure 4.2: Input for CO/Soot production in BRANZFIRE

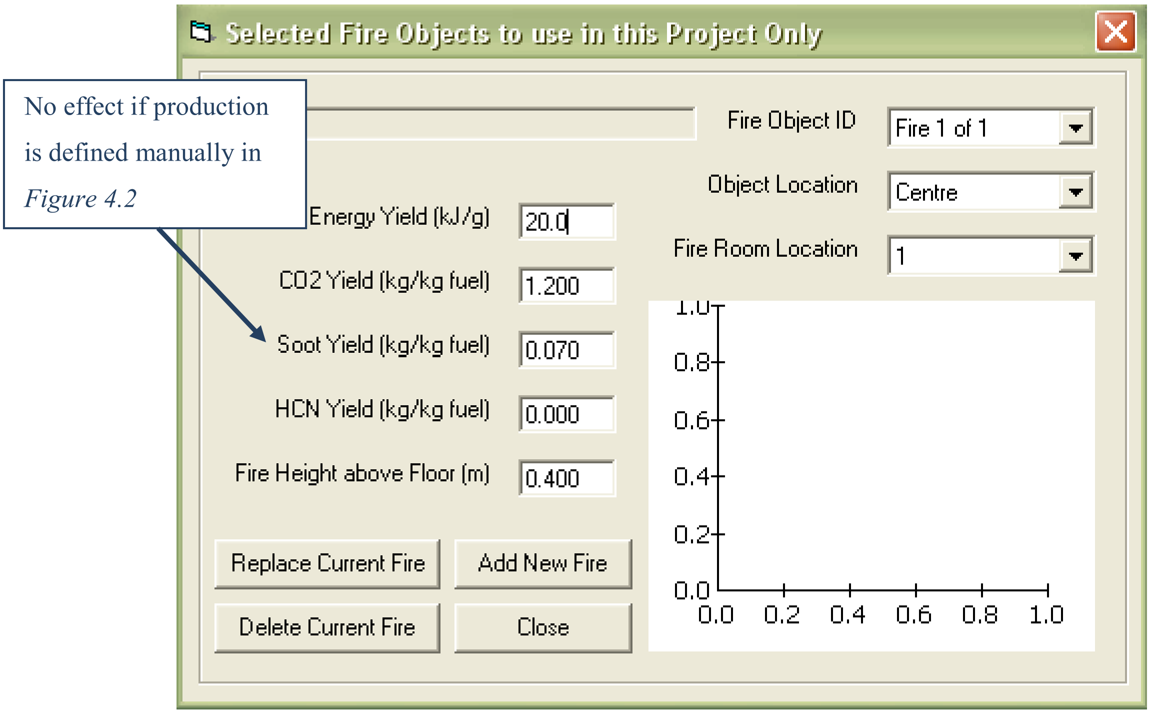


Figure 4.3: Input for fire objects in BRANZFIRE

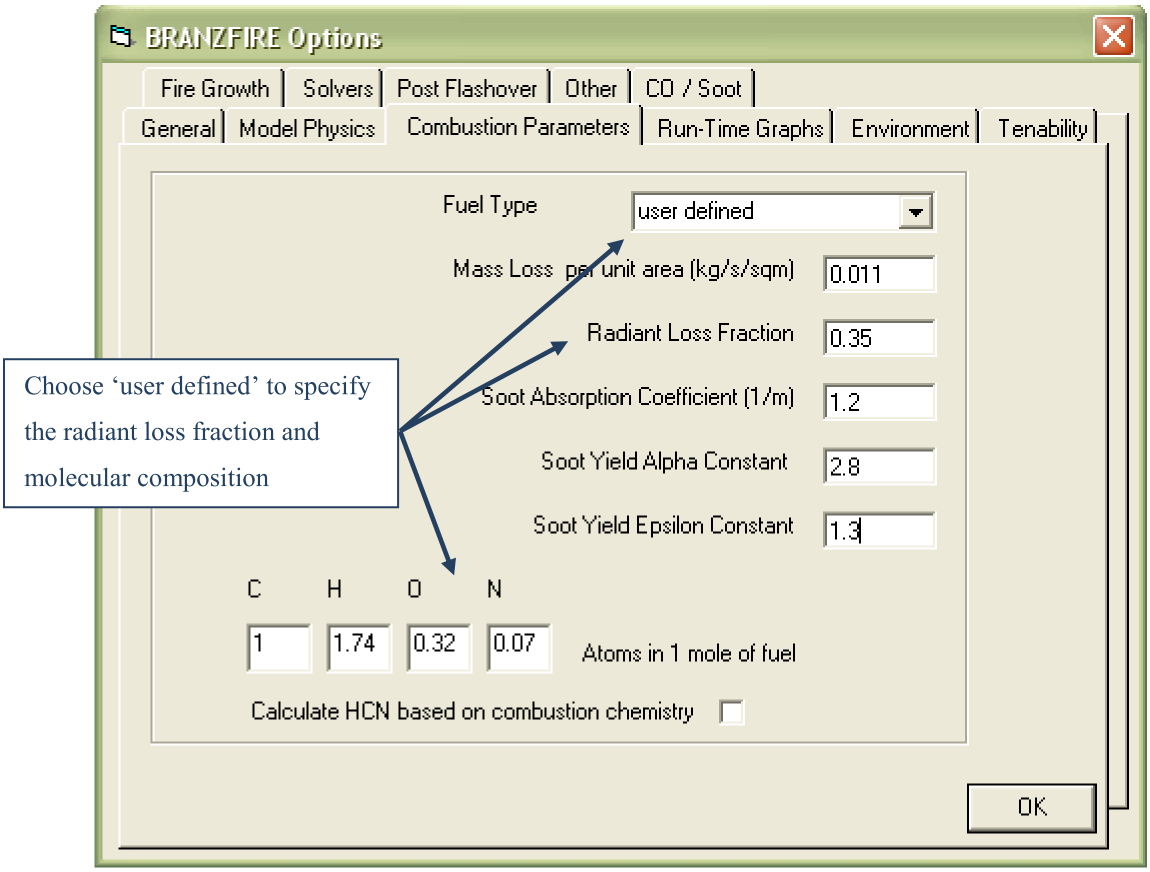


Figure 4.4: Input for combustion parameters in BRANZFIRE

4.2.2 Fire Dynamic Simulator (FDS)

Compared to zone models, computational fluid dynamics (CFD) models divide the volume under consideration into a very large number of sub-volumes and the basic laws of mass, momentum and energy conservation are applied to each of these[42]. The most widely used CFD model for fire engineering is Fire Dynamic Simulator (FDS), which solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with emphasis on smoke and heat transport from fires[45]. It yields time-varying predictions of temperature, gas velocity, species concentrations, etc. on each sub-volume.

Even though, compared to zone models, FDS is more complicated to set up the input files and the simulation is more time-consuming, it can be used to solve complicated fire problems of turbulent flow, combustion chemistry, radiation, and heat transfer at solid boundaries[46]. The simulation results can be visualized in Smokeview which is a tool for visualizing FDS results[47]. It can display time dependent tracer particle flow, animated contour slices of computed gas variables and surface data.

For this research, Fire Dynamic Simulator (FDS) was employed to run one critical fire location for each case study building, and results are compared to the BRANZFIRE zone modelling. A grid size of 200 mm was used for the Nightclub. Multiple meshes of 200 mm in room of fire origin and 400 mm in other spaces was used for the other three buildings due to the large volume of interest. The parameters of devices used in the FDS are provided in Table 4.1 compared to those in BRANZFIRE modelling.

Table 4.1: Parameters of devices in FDS

Devices	BRANZFIRE	FDS
Smoke detectors	Optical Density = 0.097 (1/m) Sensitivity = 6.6 (% per foot) Characteristic length = 15 m Radial distance = 7 m Depth below ceiling = 0.025 m	Quantity = ‘Chamber Obscuration’ Length = 15 Activation_Obscuration=9.7 (%/m) Radial distance = 7 m Depth below ceiling = 0.025 m
Standard response sprinklers (5 mm bulb)	Standard response (5mm bulb) RTI = 95 C = 0.4 Tact = 68°C Radial distance = 2.8 m Depth below ceiling = 0.02 m	Quantity = 'Sprinkler Link Temperature' RTI = 95 C_Factor = 0.4 Activation_Temperature = 68 °C Radial distance = 2.8 m Depth below ceiling = 0.02 m

The device for the radiation measurement in FDS must be attached on a solid surface. The characteristics of the solid used in the analysis are those of ‘Human skin’ having the following properties [48]:

- CONDUCTIVITY = 0.24 (W/m/K)
- SPECIFIC_HEAT = 3.5 (kJ/kg/K)
- DENSITY = 1200 (kg/m^3)

FDS results do not automatically include an estimation of FED Thermal. However, it can be calculated based on the following equations taken from ISO 13571:2007(E)[49]. The radiant heat flux can be estimated directly from FDS outputs.

$$t_{Irad} = 4.2q^{-1.9} \tag{4.1}$$

Where, q is the radiant heat flux (kW/m^2)

$$t_{Iconv} = (5 \times 10^7)T^{-3.4} \tag{4.2}$$

Where, T is temperature (^{o}C)

$$FED = \sum_{t_1}^{t_2} (1/t_{Irad} + 1/t_{Iconv})\Delta t \tag{4.3}$$

Where, Δt is expressed in minutes.

4.3 Required Safe Egress Time (RSET)

As mentioned in Section 3.7, the RSET is the sum of detection time, pre-movement time and movement time. The detection time was calculated using the fire models and the pre-movement time is specified in the proposed C/VM2. The movement time was calculated based on the hydraulic model. As the Nightclub building involves the most occupant density and merging flows in the egress calculation, Simulex (Version 11.1.3), which is an agent-based evacuation model, was employed to further evaluate the differences between the two methods.

4.3.1 Hydraulic Model

The calculation procedure using the hydraulic model has been referred to the *hydraulic model* by Gwynne S M et al. in the SFPE Handbook[35], which was incorporated into Excel at a time step of every second. Where congestion occurs in a staircase, the staircase capacity was calculated based on an occupant density of 1.9 persons/m^2. For a detailed working example, readers shall refer to APPENDIX K: Egress Calculation for the Shopping Mall.

4.3.2 Simulex

Simulex is an agent-based evacuation model which is able to simulate the escape movement of many people from large, geometrically complex building structures. It allows the user to create a 3-D model of a building by using a number of CAD-designed floor plans, connected by staircases. The algorithms for the movement of individuals are based on real-life data, collected by using computer-based techniques for the analysis of human movement, observed in real-life footage[50]. It makes a number of principle assumptions about the geometry of escape and methods of individual movement:

- Each person is assigned a normal, unimpeded walking speed;
- Walking speeds are reduced as people get closer together;
- Each person heads towards an exit by taking a direction which is at right angles to the contours shown on the chosen distance map;
- Overtaking, body rotation, sideways stepping and small degrees of back-stepping are all accommodated into the program.

The program shows the evacuation process graphically on the screen that all occupants can be viewed during the whole simulation process. Users have complete control over which part of the building is viewed at any time during the simulation. The application of Simulex to geometrically complex buildings is useful because it is able to highlight areas where queues form, flows merge, and also where exits are significantly oversized or undersized. Thompson P A & Marchant E W[51] have done a number of tests in which Simulex modelled the movement of a large number of occupants through a number of exits of different widths and results correlated well to the data obtained from real-life observations.

CHAPTER 5 CASE STUDY 1 – NIGHTCLUB

This part of the report presents the New Zealand's Case Study on a multi-storey nightclub for the 2010 SFPE 8th International Conference on Performance-Based Codes and Fire Safety Design Methods[52]. Two design strategies are described including the acceptable solution according to the requirements in the approved document C/AS1 and a performance-based fire safety engineering design, both followed by C/VM2 analysis. The design should meet the following fire and life safety goals:

- Safeguard occupants from injury due to fire until they reach a safe place;
- Safeguard firefighters while performing rescue operations or attacking the fire;
- Maximize the number of occupants that can safely be admitted to the nightclub.

5.1 Introduction

Buildings with assembly occupancies, such as night clubs, have history of lost large number of lives due to use for crowded public and the potential for rapid fire growth, which makes fire engineering assessment more challenging. In 1940, the Rhythm Club fire in U.S took 207 lives and injured 200 more of the 700 occupants[53]. The fire started from the highly combustible Spanish moss over the dance floor. There was only one main exit, which was partially blocked, with doors open inward. Two years later, the Cocoanut Grove nightclub fire took 492 lives and became the deadliest nightclub fire in U.S. history[54]. The fire began in the area of artificial palm trees and highly combustible decorations in the basement Melody Lounge. At the time of the fire, the building was well over capacity with over 1,000 occupants. In 1977, the Beverly Hills Supper Club fire took 165 lives and 70 other people injured[55]. The reported cause of fire was electrical in nature and started from combustible material in a concealed space in the ceiling. In more recent nightclub fires, the Station nightclub fire in U.S. 2003 caused 100 fatalities[56]. The fire started on the combustible material on the wall around the stage when pyrotechnic devices where activated. The Lame Horse fire in Russia 2009 killed over 150 of the nearly 300 occupants[57]. The fire started when sparks from fireworks ignited the low ceiling and its willow twig covering.

The major common contributing factors in these historic nightclub fires include:

- No sprinkler system provided;
- Combustible interior finishes causing rapid fire spread with large quantities of toxic smoke;
- Either insufficient egress or poor egress signage;
- Locked or blocked egress doors and open into wrong direction (inwards);
- Occupants unfamiliar with the building;

- Over crowded occupancies[58];
- Storage of combustibles in improper locations;
- Improper use or insufficient control of open flames, e.g. pyrotechnic devices and fireworks.

Because the nightclub buildings are concerned with hazards of large number of occupants gathered in one area and large quantities of highly combustible materials with rapid fire growth, fire in this type of buildings can put large number of people at risk and challenge the Building Code. This chapter presents a case study for a 'Change of Use' of an office building into a four story nightclub. The building includes a number of fire engineering challenges due to the limited number and size of the egress routes and the potential for a large number of occupants that may be intoxicated.

5.2 Building Description

The nightclub building has four levels including a basement. The ceiling height between each level is 3.0 m. As shown in Figure 5.1, the basement (Floor 0) contains an open foyer that links two stairways providing access to the ground floor. There is a large open bar area with the remaining floor area including toilets, offices, storage, mechanical space, and backstage area. Egress from the bar area is shown by the dotted (green) arrows. Egress from the basement level is either via western open stairway to the ground floor dancing area which has direct egress to the outside, or via the eastern stairway to the ground floor corridor leading to the outside as shown by the solid (red) arrows.

The ground floor (Floor 1) contains the main entrance for the night club and a second western entrance from street that directly accesses Floor 2 and all upper floors via a stairway as shown in Figure 5.2. Inside the main entrance is a stage, dance floor, bar and wardrobe. A second larger bar area is located in the rear of this level as well as a kitchen and other service areas. The western open stairway beside DJ provides egress from the basement. The open stairway beside storage provides egress to Floor 2. The eastern stairway beside the kitchen provides egress from all levels and discharge people to outside via a corridor. Egress from the bar area is shown by the dotted (green) arrows and final egress of the building is shown by the solid (red) arrows in Figure 5.2.

Floor 2 contains partial floor area with access to the lower roof over Floor 1. It contains a stage dance floor, bar and wardrobe area as well as a number of small service rooms. The ceiling over the dance area is open to Floor 3 above. Egress from this floor can be via two enclosed staircases as shown by the solid (red) arrows in Figure 5.3.

Figure 5.4 shows the floor plan of Floor 3, which includes a large opening in the floor to Floor 2 with an open balcony to allow patrons to over look the dance floor and stage area below as illustrated in Figure 5.5. There is also a small bar, toilets, backstage room and storage room. Egress from this level is provided by the two staircases as shown by the solid (red) arrows.

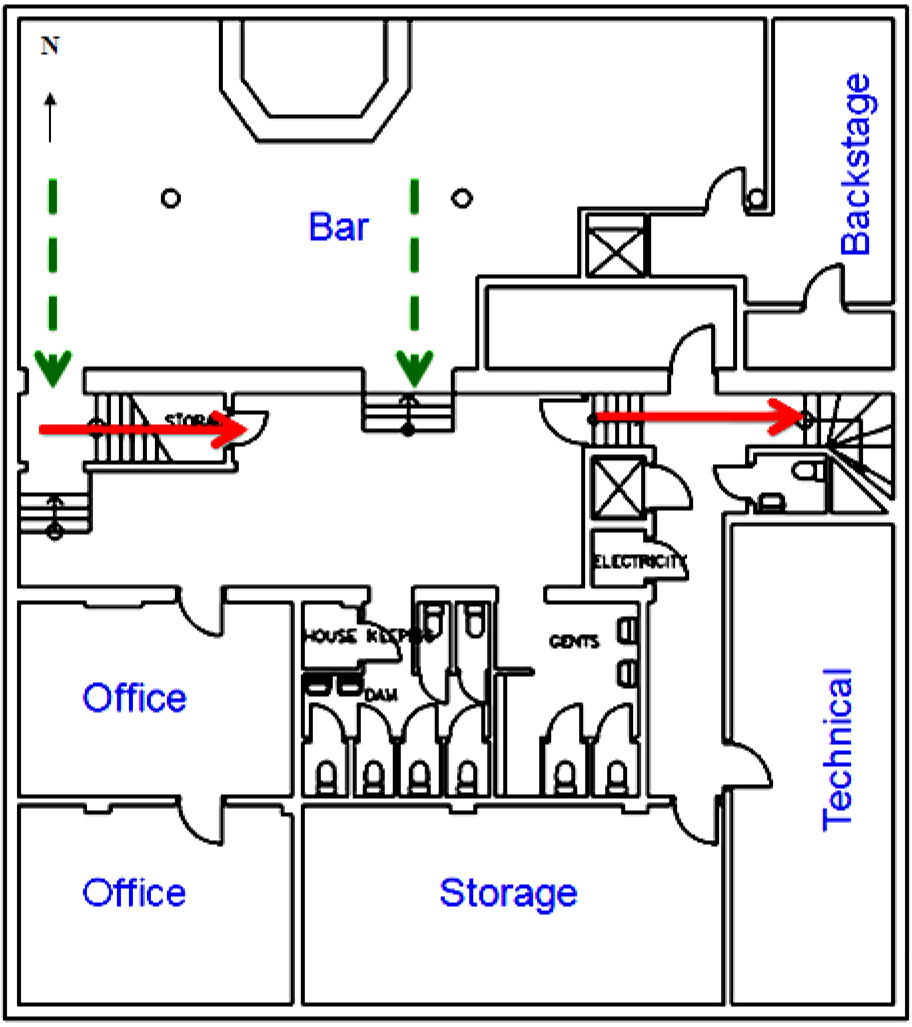


Figure 5.1: Floor plan of the proposed nightclub – Basement (Floor 0)

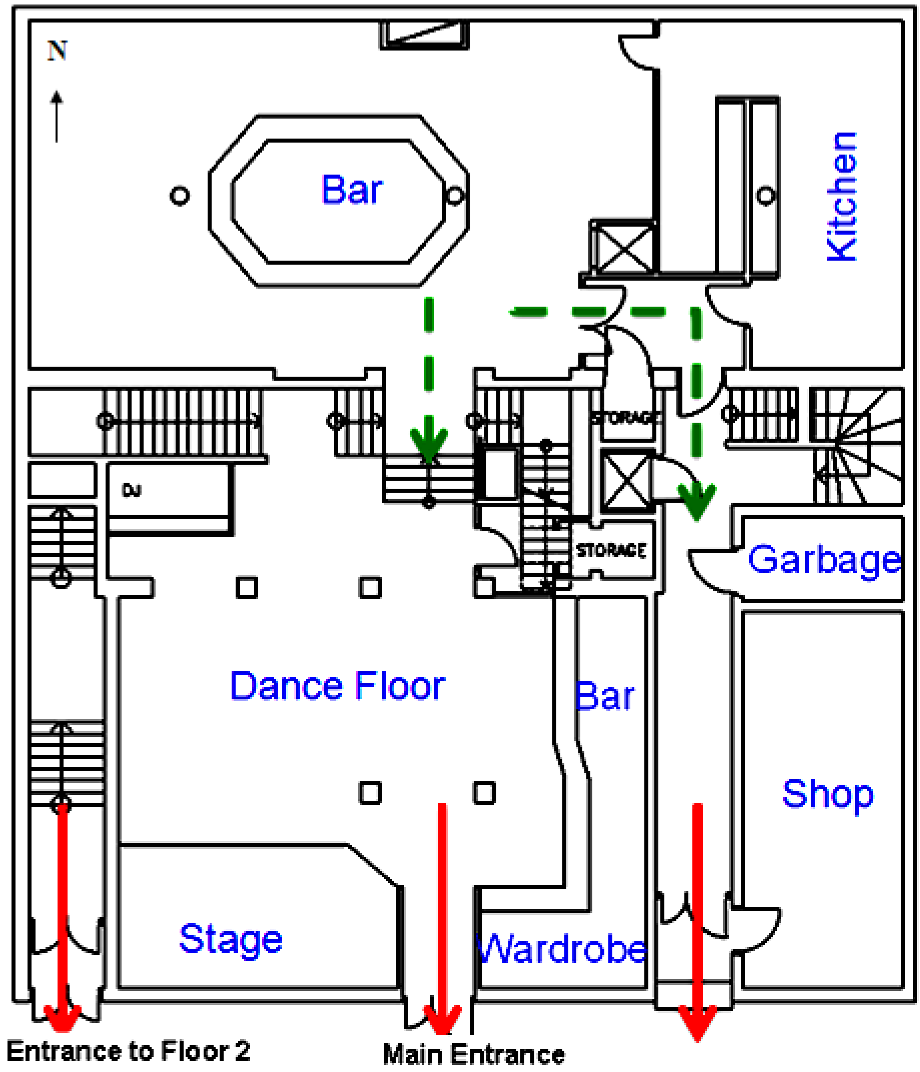


Figure 5.2: Floor plan of the proposed nightclub – Ground Floor (Floor 1)

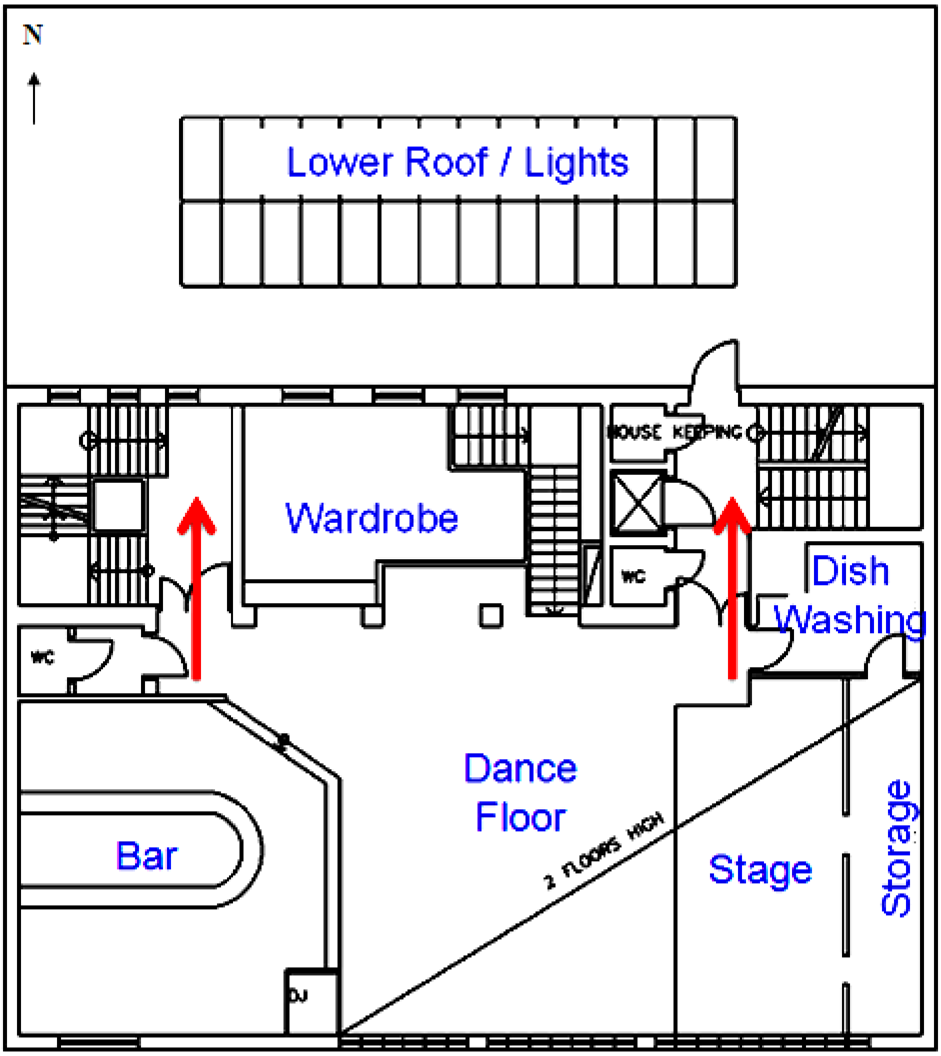


Figure 5.3: Floor plan of the proposed nightclub – Floor 2

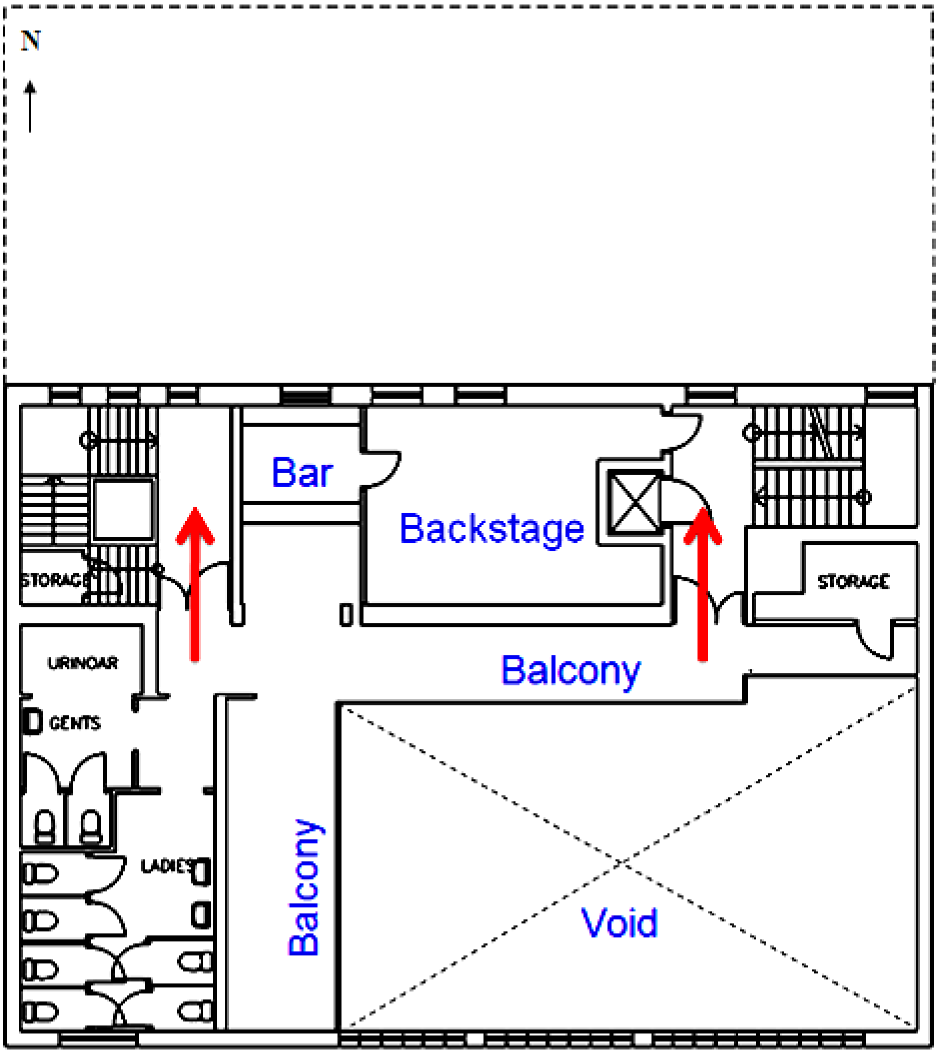


Figure 5.4: Floor plan of the proposed nightclub – Floor 3

Figure 5.5: Photo illustrates the atrium space of the proposed nightclub on Floor 2 & 3

5.3 C/AS1 Design

5.3.1 Purpose Groups, Fire Hazard Category and Occupant Loads

The purpose group and occupant loads are primary parameters to determine means of egress and other fire safety precautions. The Purpose Group (PG) and Fire Hazard Category (FHC) for this building were taken from *Table 2.1 C/AS1* (refer to APPENDIX B). The occupant load was calculated from occupant densities taken from *Table 2.2 C/AS1* (refer to APPENDIX C) and the floor area. The building has total occupants of 818 as shown in Table 5.1. Spaces, such as storage, wardrobe, backstage, toilet facilities etc. used for intermittent activities, were not assessed for occupant loads. However, occupants shall be counted for the balcony areas on Floor 3 that overlooks Floor 2.

Table 5.1: Purpose Group, FHC and Occupant Load - Nightclub

Location		PG	FHC	Occupant Density (persons/m^2)	Area (m^2)	Occupant Load (persons)
Floor 0 (Basement)	Bar	CL		2	90	180
	Office1	WL		0.1	21.5	2
	Office2	WL		0.1	22	2
	Technical	WL	2	0.03	30.7	1
Total occupant loads on Floor 0						**185**
Floor 1 (Ground floor)	Bar	CL		2	91	182
	Kitchen	WL		0.1	33	3
	Dance Floor	CL		1.7	62	105
	Bar counter	WL		0.1	11	1
	Stage	CS		1.3	17	22
	Shop	CM		0.3	26	8
	DJ	WL	2	-	-	1
Total occupant loads on Floor 1						**322**
Floor 2	Bar	CS		2	38	76
	Dance Floor	CL		1.7	63	107
	Stage	CS		1.3	22	29
	DJ	WL	2	-	-	1
Total occupant loads on Floor 2						213
Floor 3	Bar (incl. Balcony)	CS	2	2	49	98
Total occupant loads (Floor 3)						**98**
Total occupant loads of the building:						**818**

5.3.2 Requirements for Firecells

Under C/AS1, the building is divided into the following firecells to control fire spread as shown in Figure 5.6 to Figure 5.9 for each level.

- The basement, ground floor and top two floors shall be separate firecells respectively. This requires that the open stairway serving floors 0-1 and stairway serving floors 1-2 must be closed off with fire separations;
- Floor 2 & 3 are contained in one firecell and considered as a Limited Area Atrium firecell;
- The western stairway serving floors 1-5 and eastern stairway serving all levels shall be enclosed as safe paths and provide egress directly to a safe place;
- Communicating space connected to the two stairways at the basement level shall be enclosed as a smokecell;
- All lifts and service shafts shall be enclosed within protected shafts.

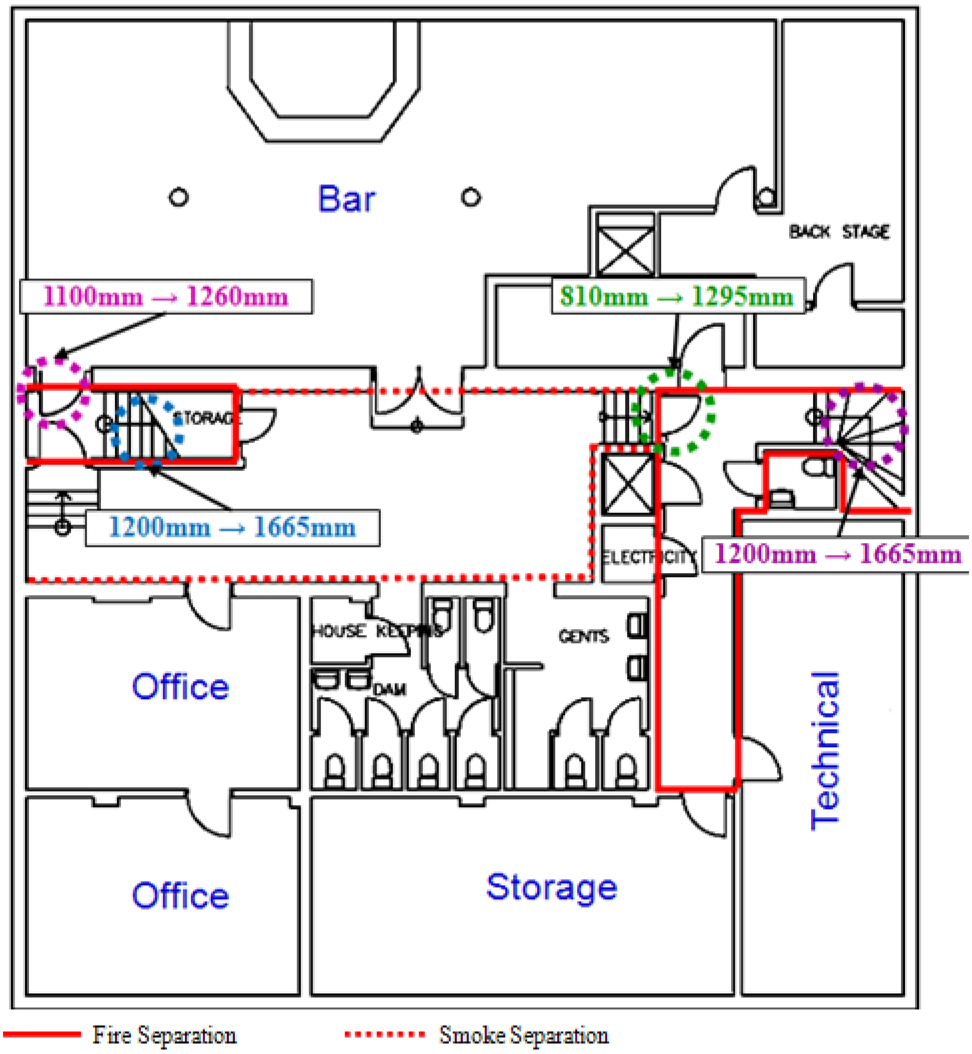


Figure 5.6: Firecell separation & egress modification of the proposed nightclub on Floor 0

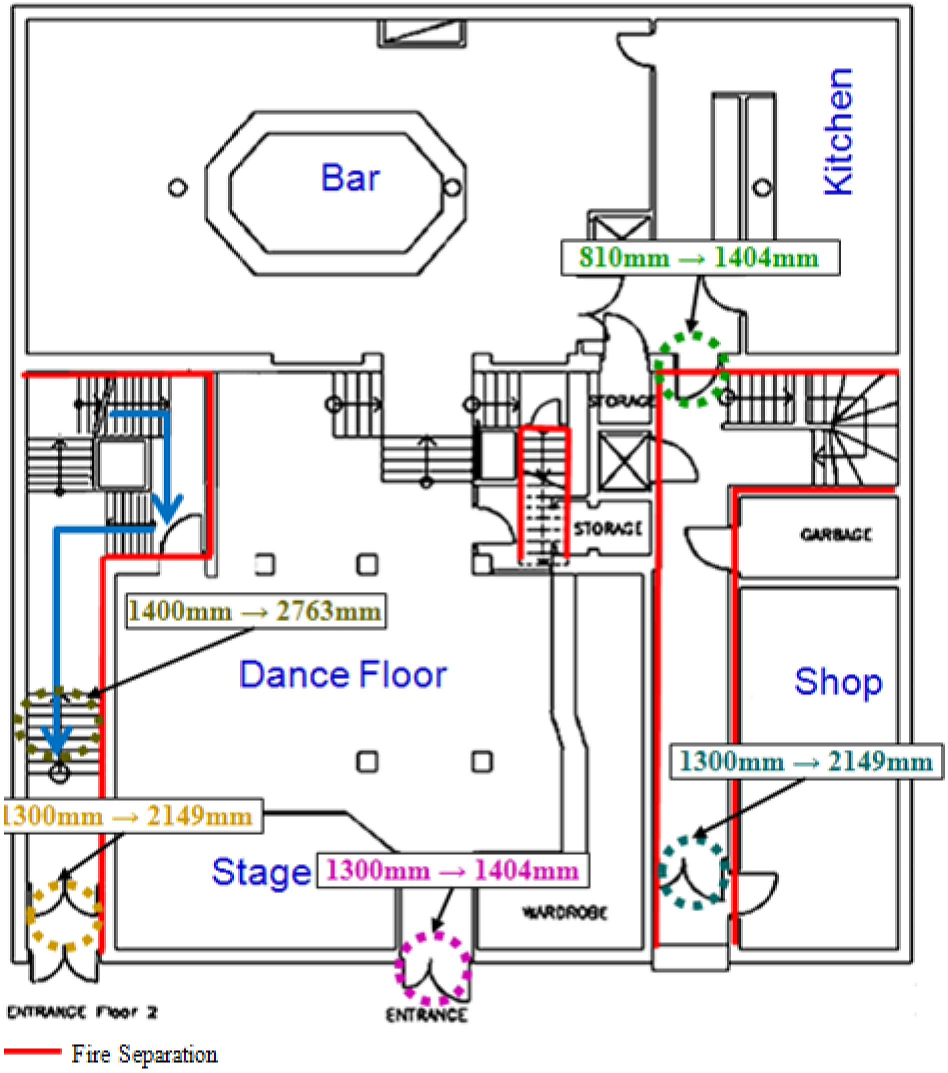


Figure 5.7: Firecell separation & egress modification of the proposed nightclub on Floor 1

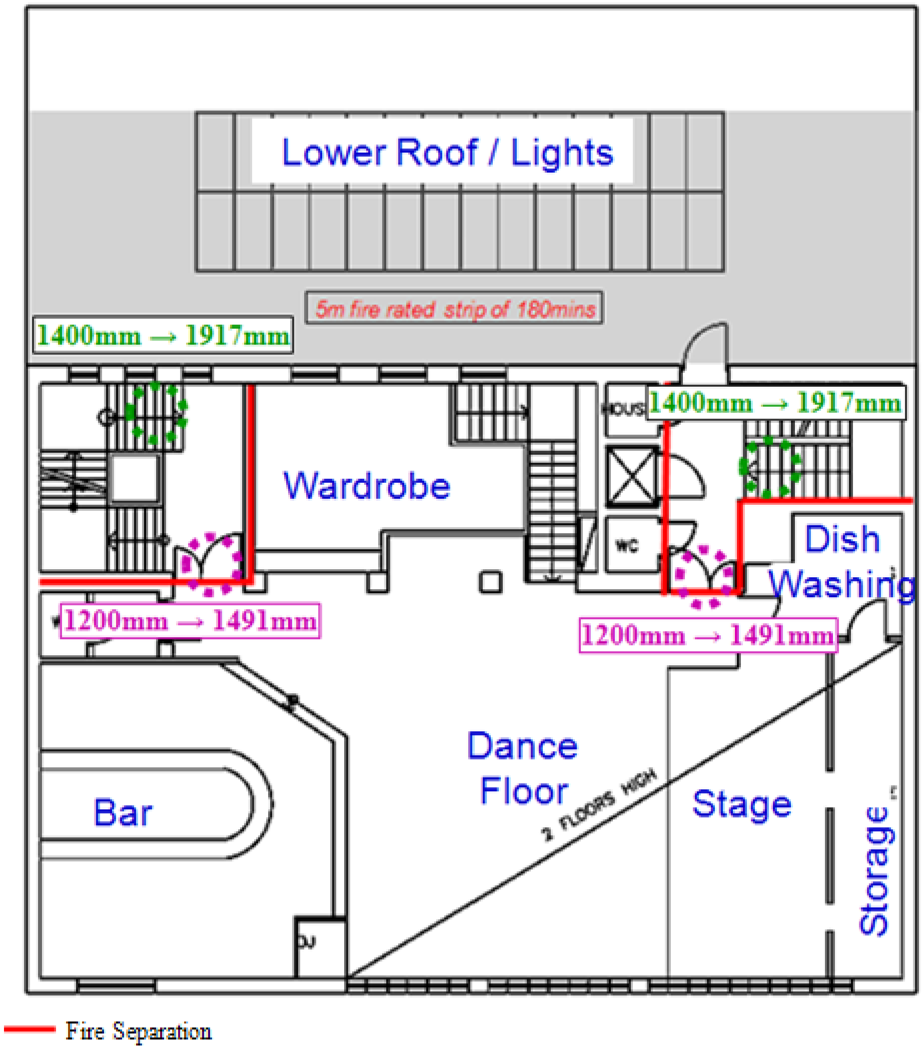


Figure 5.8: Firecell separation & egress modification of the proposed nightclub on Floor 2

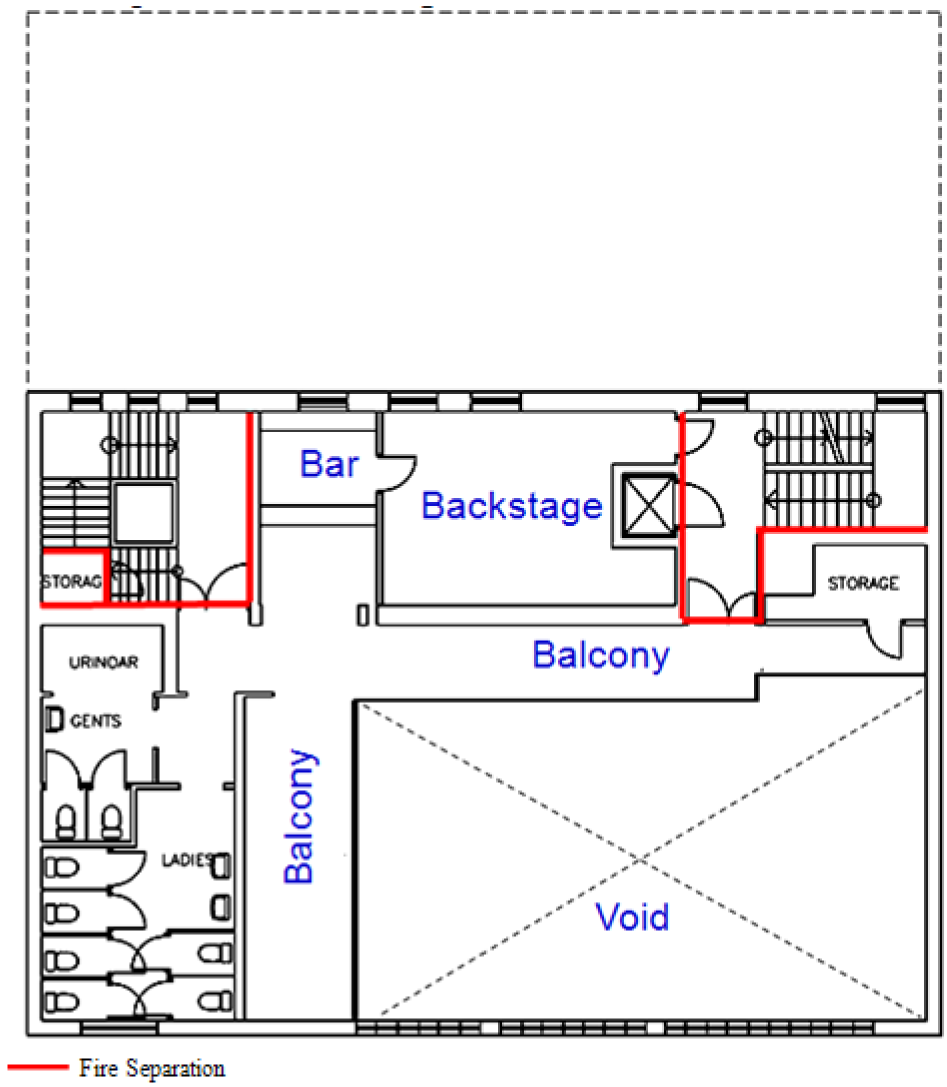


Figure 5.9: Firecell separation & egress modification of the proposed nightclub on Floor 3

As per *Clause 6.22.2 C/AS1*, the following fire design features are required for the Limited Area Atrium firecell, including:

- At least one of the staircases shall be enclosed as a safe path; and
- Smoke detectors, as well as manual call points, shall be installed throughout the firecell; and
- A smoke reservoir and mechanical smoke extract are required over the atrium space.

For this building height and occupancy, the minimum firecell ratings, alarm types and fire safety systems are summarised in Table 5.2. It shall be noticed that, as per *Clause 4.5.13 C/AS1*, where firecells containing the same purpose group occur at different levels in the same building, the FSPs required by *C/AS1 Table 4.1* (refer to APPENDIX G) for the firecell having the greatest escape height, shall be applied to all firecells in that purpose group.

Table 5.2: Fire Safety Precautions – Nightclub

Firecell Location	Escape Height (m)	PG	F Rating (minutes)	Alarm Type	Other Protection Required
Floor 0 (Basement)	3	CL	60	HD, MCPs	▪ Smoke control in air handling system ▪ Visibility in escape routes
Floor 1 (Ground)	0	CL	0	HD, MCPs	▪ Smoke control in air handling system ▪ Visibility in escape routes
Floor 2 & 3 (Atrium)	6	CL	60	SD, MCPs	▪ Smoke control in air handling system ▪ Mechanical smoke extract ▪ Visibility in escape routes

Key: HD – Heat detectors SD – Smoke detectors MCPs – Manual Call Points

According to Table 2.3, the floor area of an unsprinklered firecell shall not exceed 2500 m^2 for building under FHC 2. The firecell floor area may be unlimited where a firecell is sprinklered, unless when purpose groups require subdivision or other area limitations are imposed. As the nightclub building has floor area much less than 2500 m^2 that this requirement has been satisfied.

5.3.3 Means of Escape

5.3.3.1 Special Conditions for Crowd Purpose Group CL

As per *Clause 3.16 C/AS1*, any firecell containing purpose group CL shall be served by safe paths or final exits connecting directly to that firecell. The number of safe paths shall comply with Table *3.1 C/AS1* (refer to APPENDIX D) for the occupant load. Entrances to vertical safe paths from upper and intermediate floors shall be preceded by protected paths except where:

- The safe path from an upper floor or intermediate floor serves only that floor, or
- The firecell is sprinklered, or
- The occupant load of the firecell is less than 150, or
- A voice communication system is installed and an approved staged evacuation scheme is operable.

As per *Clause 3.7 C/AS1*, safe path serving basement firecells shall be preceded by a protected path, except where there are two or more escape routes serving only the basement firecells. The floor area of the protected path is calculated as per *Clause 3.4.5 C/AS1*, which shall have capacity for 141 occupants. The occupant density for calculating the required holding area is 4.0 persons/m^2.

To meet the above Clauses, the following design features are required, including:

- Each CL firecell requires at least two safe paths or final exits connecting directly to that firecell. Therefore, the western open stairway from the basement to the groundfloor will be enclosed as safe path as shown in Figure 5.6. The second entrance on the ground floor, which provides direct access to upper floors, shall be enclosed as a safe path and be able to provide egress from the basement as well, as shown in Figure 5.7;

- Two safe paths serving the basement shall be preceded by protected paths and require total holding area of no less than 36 m^2, which means the communicating space at basement level shall be enclosed as a smokecell as shown by red dotted lines in Figure 5.6;
- Entrances to the two stairways on Floor 2 & 3 shall be preceded by protected paths, which is not desirable according to the floor plan. Therefore, either a voice communication system with an approved staged evacuation scheme must be provided, or the building is required to be sprinklered.

5.3.3.2 Number and Width of Escape Routes

The required number of escape routes is based on the occupant loads being considered in accordance with *Table 3.1 C/AS1* shown in Appendix D. Width of escape routes is determined by the combined width based on the occupant loads or minimum individual width whichever is greater in accordance to *Table 3.2 C/AS1* shown in APPENDIX E.

In unsprinklered firecells the required combined width shall still be available should one of the escape routes be unusable as per *Clause 3.3.2 C/AS1*, which means if minimum of two escape routes are required, each shall be sized for the required total combined width. Where the firecell is sprinklered it is unnecessary to provide extra width to allow for the possibility that one escape route may be unusable. It shall be noticed where a final exit on the ground floor joined by an escape route from basement, the escape route width shall be increased to accommodate the occupant loads from both directions.

The required / available number and width of escape routes are summarised in Table 5.3. The results show that where the building is unsprinklered, significant modification will be required to provide sufficient egress on Floor 0-3 as illustrated in Figure 5.6 to Figure 5.8. Where the building is sprinklered, there is no need to provide extra width for escape routes except that doors on the ground floor, which are required to provide for people with disabilities, shall have minimum clear width of 850 mm. For example, where the building is unsprinklered, each of the two egress doors from the basement bar shall be able to provide clear width of 1260 mm considering the widest door unusable. Where the building is sprinklered, only the total width of the two egress doors shall provide clear width of 1260 mm.

Table 5.3: Width and Number of Escape Routes in the nightclub

	Location	Serving Occupancy (persons)	Number of Egress Required	Number of Egress Available	Type of Travel	Width - unsprinklered (mm) Required	Width - unsprinklered (mm) Available	Width – sprinklered (mm) Required	Width – sprinklered (mm) Available
Floor 0						1260	***1100***		
	Bar	180	2	2	H	1260	1800	1260	2900
	Office 1	2	1	1	H	700	810	700	810
	Office 2	2	1	1	H	700	810	700	810
	Technical	1	1	1	H	700	810	700	810
	Corridor door					1295	***810***		
	West stair door	185	2	2	H	1295	***810***	1295	1620
						1665	***1200***		
	Stairs	185	2	2	V	1665	***1300***	1665	2500
Floor 1						1274	1800		
	Bar	182	2	3	H	1274	1300	1274	3100
	Shop	8	1	1	H	850	***810***	850	***810***
	Corridor door					1404	***1300***		
	Main Entrance					1404	***810***		
	West stair door	322	2	3	H	850	***810***	2254	2920
	East corridor					2149	***1300***		
	West exit	307	2	2	H	2149	***1300***	2149	2600
Floor 2						1491	***1200***		
	Stair doors	213	2	2	H	1491	***1200***	1491	2400
						1917	***1400***		
	Stairs	213	2	2	V	1917	***1400***	1917	2800
Floor 3						850	1200		
	Stair doors	98	2	2	H	850	1200	850	2400
						1000	1400		
	Stairs	98	2	2	V	1000	1400	1000	2800

*The values shown in **bold-italics** do not comply with C/AS1*

5.3.3.3 Length of Escape Routes

For purpose group CL, the open path lengths may be increased for 20 % where heat detectors are installed, or 100 % where sprinklers are installed or 100 % where smoke detectors are installed. The increases may be combined but no greater than twice. No increase is allowed for protected paths.

The maximum allowed length of escape routes have been addressed using *Table 3.3 C/AS1* (refer to APPENDIX F), and summarised in Table 5.4 where only heat detectors will be installed on Floor 0 & 1 and smoke detectors on Floor 2 & 3. The results show that the travel distances in each case are within those allowed by C/AS1. Where sprinklers are installed throughout the building that more increases are allowed, the travel distances will still comply.

Table 5.4: Length of Escape Routes without sprinkler - Nightclub

Location		PG	Dead End Open Path (m)		Total Open Path (m)		Protected Path (m)	
			Allowed	Actual	Allowed	Actual	Allowed	Actual
Floor0	Bar	CL	21.6	19	54	29	45	11
	Office1	WL	28.8	8	72	31.5	60	5.5
	Office2	WL	28.8	14	72	37.5	60	5.5
	Technical	WL	28.8	20	72	27.5	60	1.5
Floor1	Bar	CL	21.6	20	54	37	-	-
	Kitchen	WL	28.8	12.4	72	27	-	-
	Dance & Bar	CL	21.6	0	54	17	-	-
	Stage	CS	21.6	0	54	11	-	-
	Shop	CM	28.8	11	72	13	-	-
	DJ	WL	28.8	0	72	18	-	-
Floor2	Bar	CS	36	0	90	26	-	-
	Dance Floor	CL	36	0	90	24	-	-
	Stage	CS	36	0	90	28	-	-
	DJ	WL	48	0	120	19	-	-
Floor3	Bar	CS	36	6	90	18	-	-

5.3.4 Internal and External Spread of Fire and Smoke

5.3.4.1 Fire Resistance Ratings

As the building is under one ownership, the required fire rating throughout the building is the F-rating except along any boundary. The safe path staircases shall be separated from adjoining firecells by fire separations having the same FRR throughout its length. The FRR shall be the greater of F30 or the F rating of the highest rated adjoining firecell, which is F60. Fire doors to the safe path stairs shall have the same rating as stairs -/60/60*Sm* fitted with self closer and vision panels.

As per *Clause 6.14 C/AS1*, floors shall be rated on the underside. The FRR shall be that rating applicable to the firecell directly below the floor. Intermediate floor (Floor 3) and their supporting primary elements within the firecell shall have FRR of no less than 15/15/15 where the area under the intermediate floor is unenclosed.

It is assumed there is no adjacent property, the building has no sleeping occupants, and the building height is less than 10 m. Hence, external walls are allowed to have 100% unprotected area. However, fire spread from a roof lower than an external wall shall be avoided where firecells behind the wall contain purpose group IE. Roof protection shall be provided either by installation of sprinklers in the firecell below the roof, or constructing that part of the roof within 5 m horizontally of the wall, with a FRR of 180 minutes derived from the S rating of the firecell below the roof as shown in Table 5.5.

Table 5.5: S Rating of Lower Roof over the ground floor

Variable	Value
A_v/A_f	<0.05
A_h/A_f	0
FHC	2
t_e *(from Table 5.1 C/AS1)*	180
k	1.0
S Rating = $k \cdot t_e$	180 minutes

5.3.4.2 Interior Surface Finishes

The interior surface finishes of the walls, ceilings, floor linings, and air ducts serving more than one firecell in purpose groups IE, CS, CL, CM and WL, shall have surface finishes satisfying the following requirements as shown below in Table 5.6. In firecells constructed without foamed plastics, and equipped with sprinklers, only the ceiling need to comply with the SFI and SDI requirements.

Table 5.6: Requirements for Surface Finishes in the nightclub

Building Elements	Purpose Group or Location	SFI	SDI	FI
Walls, Ceilings	Exit way	0	3	-
	All occupied spaces in purpose groups CS & CL	2	5	-
	Passageways, corridors and stairways not being part of an exitway	7	5	-
	Minimum requirement for all occupied spaces in all purpose groups	5	10	-

Building Elements	Purpose Group or Location	SFI	SDI	FI
Flooring (Coverings)	Exitways	Non-combustible or have low radius of effects of ignition		
Ducts for HVAC systems	Internal surfaces	0	3	-
	External surfaces	7	5	-
Suspended flexible fabrics	All occupied spaces in CS & CL including exitways	-	-	12
	Underlay to exterior cladding or roofing when exposed to view in occupied spaces in purpose groups WL, CM, CS, CL & IE	-	-	5
Membrane structures	Purpose groups CM, CS & CL	-	-	12

Key: SFI = spread of flame index SDI = smoke developed index FI = flammability index

Where foamed plastic building materials are used in wall, ceiling or roof systems, they shall meet the following requirements as shown in Table 5.7.

Table 5.7: Requirements for foamed plastics materials in the nightclub

Application	Required Properties
Exitways unsprinklered	fb + p
Exitways sprinklered	fb + p
Non-sleeping occupied spaces unsprinklered	fb + p
Non-sleeping occupied spaces sprinklered	sf + p
Concealed spaces	p

Key: p – foamed plastics shall comply with the flame propagation criteria as specified in AS 1366
fb – flame barrier complying with Appendix C C9.1 of C/AS1

5.3.4.3 Smoke control System

Smoke control in limited area atrium firecell is required for sufficient time to allow occupants to safely escape to a safe place. As per *Clause 6.22.9 C/AS1*, a smoke reservoir shall be no greater than 1000 m^2 in plan area and have a maximum dimension of 60 m in any direction. The atrium space of the nightclub is 11.2 m long by 6.7 m wide with plan area of 75 m^2, which satisfies the clause. The ceiling of the smoke reservoir shall be constructed at least 1 m higher than the ceiling level over the highest occupied floor. Hence, the ceiling height over the atrium space shall increase by 1 m.

The extract capacity of the mechanical smoke extract system and required inlet area are specified according to *Table 6.6 C/AS1*. Total extract rate out of smoke reservoir shall be 19 m^3/s and free inlet area for make-up air shall be 2.9 m^2. Minimum of two extract points are required.

The mechanical smoke control system is required to:

- Be independent of any other ventilation system in the building;
- Be activated by the smoke detection system;
- Have a manual control located in a position approved by the Fire Service;
- Be capable of operating independently of or in conjunction with the fire mode of any other ventilation system in the building;
- Be protected from the effects of fire to ensure continuous operation for no less than 60 minutes from the time smoke is detected;
- Be equipped with exhaust fans capable of running continuously in temperatures of 40^{o}C and for no less than 60 minutes in the maximum air/smoke temperature from the fire, or 200 ^{o}C.

5.3.5 FireFighting

The building is considered having Fire Service vehicular access within 18m on the south side of the building. Fire hydrant system is not required as Fire Service access is within 75 m from the Fire Service vehicular access to any point on any floor. According to *Clause 8.2.4 C/AS1*, in a building not required to have a fire systems centre, the control features shall contain all control panels indicating the status of fire safety systems installed in the building, together with all control switches. Hand operated firefighting equipments, e.g. fire extinguishers, shall be provided and installed in compliance with *NZS 4503:2005 Hand Operated Fire-fighting Equipment*[59].

5.3.6 Summary of Design and Modification to Comply With C/AS1

The following design features or egress modifications are required to comply with C/AS1. There are three design methods are provided whilst Design 1 & 2 are not recommended. For building not sprinklered, large floor area must be modified into egress routes as well as a sound stage evacuation scheme or limit the allowable number of occupants into the building, which are hardly to be achieved in reality for this type of building use. The best practice is to provide sprinkler system in the building which requires less fire ratings, no significant egress modification and no stage evacuation scheme.

5.3.6.1 Design 1 – Without sprinkler system

- The building shall have fire / smoke separations as mentioned in Section 5.3.2.
- For the means of escape, the western staircase shall be modified to provide egress from basement level as shown in Figure 5.7. Widths of escape routes shall be increased with reference to Table 5.3;
- Heat detectors will be installed at basement and ground floor, smoke detectors on Floor 2 & 3. Detectors shall be interconnected. Direct connection to fire service is not required if telephones are installed and freely available at all times to enable 111 calls to be made;

- Voice communication system with an approved staged evacuation scheme must be provided for limited area atrium firecell on Floor 2 & 3;
- Open stairway from ground floor to Floor 2 shall be closed off with fire separation. Western open stairway at basement level shall be enclosed as safe path. Staircases access to all levels shall be enclosed as safe paths and have FRR of 60/60/60. Lower roof over Floor 1 shall have a 5 m FRR strip of 180 minutes;
- Communicating space at basement level shall be enclosed as a smokecell;
- Mechanical smoke extract is required over atrium having exhaust capacity of 19 m^3/s and free inlet area of 2.9 m^2. Two extract points are required; Floor 4 would have to be modified to accommodate at least a partial reservoir above the atrium area on Floor 3;
- Illuminated exit signs are required throughout the building in accordance with *F8/AS1*;
- Emergency lighting is required throughout the building in accordance with *F6/AS1*;
- Fire hydrant riser shall be provided to facilitate firefighting;
- Interior surfaces shall meet all requirements in Table 5.6 & Table 5.7.

5.3.6.1 Design 2 – Limit the number of occupants

All of the fire safety features included in Design #1 above still apply to this design. The only change is a reduction in the allowable number of occupants such that there is no change required to the means of escape. ***This methodology is not recommended for this type occupancy as experience has shown that nightclubs are prone to overcrowding with disastrous results.*** The author does not expect that the owner is likely to be able to control the number of occupants to the level given here and that this design is only included as an academic exercise.

Table 5.8 summarises the revised occupant numbers assuming that the occupant loads are based on the available egress capacities. The basement, ground floor and Floor 2 will require reduction. The basement occupant load is reduced because the open stairway cannot be counted as an available exit which is open to the ground floor and does not lead directly to a safe place. Thus the basement is considered as a single means of escape and the occupant load is limited to 50 people. The ground floor is limited by the 810 mm exit door into the egress corridor at the North end of the eastern corridor. Allowing for 7 mm/person, the capacity of an 810 mm door is limited to 115 occupants. Floor 2 is limited by the 1400 mm staircase allowing for 155 occupants. Occupancy on Floor 3 is based on the floor area and occupant density in accordance with C/AS1. Hence, for the entire building, the maximum occupant loads based on the occupant density in C/AS1 is 818, while the allowable number of occupants based on the available egress routes is 418.

Table 5.8: Revised occupant loads based on available egress capacity for the nightclub

Level	Maximum Occupancy	Allowable Number of Occupants	Controlling Feature
Floor 0 (Basement)	185	50	Single means of escape (Open stairway not counted)
Floor 1 (Ground)	322	115	Door entering in corridor 810mm
Floor 2	213	155	Staircase width of 1400mm
Floor 3	98	98	Occupant/floor area according to C/AS1
Entire Building	**818**	**418**	

5.3.6.2 Design 3 – With sprinkler system

Most of the fire safety features included in Design #1 still apply to this design with the following amendments:

- No increase is required for the widths of escape routes;
- The building is sprinkler protected throughout. Sprinkler system shall be designed and installed in compliance with *NZS 4541:2007 Automatic Fire Sprinkler Systems*[60]. Heat detectors are not required on Floor 0 & 1. Voice communication system is not required in Atrium firecell;
- The FRR for all fire separations can be reduced by 50% which is 30 minutes. Fire rating on lower roof over the ground floor does not required.

5.4 C/VM2 Analysis

5.4.1 DFS 1 – Challenging Fire

According to the proposed C/VM2, any room or space having area greater than 200 m^2 or with occupant loads greater than 150 requires analysis under DFS 1, including Bar on Floor 0 (basement), Bar on Floor 1 (ground floor) and atrium space on Floor 2. Even though the Dance Floor on the ground floor has total occupant loads originally less than 150, occupants from the basement and upper floor will egress through the Dance Floor to the main exit. Hence, the Dance Floor serving over 150 occupants has great fire concerns and was analysed as well. All other rooms are less than 200 m^2 and have less than 150 occupants and therefore do not require analysis under DFS 1.

5.4.1.1 ASET – BRANZFIRE Modelling

BRANZFIRE modelling was used to determine the Available Safe Egress Time (ASET). The design fire parameters are specified as the proposed C/VM2. An example input file in BRANZFIRE for fire in the bar at basement level is attached in APPENDIX H-1. The building construction materials for interior walls, ceilings and floors are summarised in Table 5.9.

Table 5.9: Construction materials as modelled in BRANZFIRE – Nightclub

	Wall	Ceiling	Floor
Surface	16mm plasterboard	100mm concrete	100mm concrete
Substrate	100mm concrete	-	-

(1) Bar Fire in Basement

Figure 5.10 shows the geometry of the Basement level modelled in BRANZFIRE including the bar area where the fire originates, the foyer, corridor and two staircases forming the egress routes from the basement level. Those minor rooms not having significant impact on the results were not included in the modelling but still considered in the egress calculation.

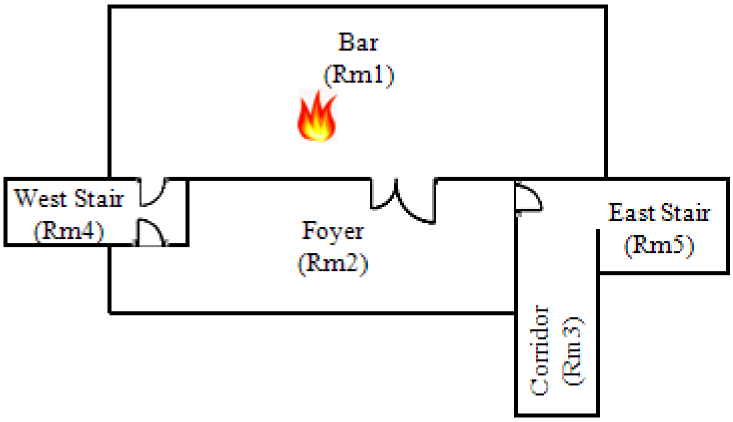


Figure 5.10: Geometry as modelled in BRANZFIRE – Bar fire in basement

Table 5.10 gives the details of room geometries in BRANZFIRE modelling for both sprinklered (original egress width) and unsprinklered (increased egress width) cases, e.g. width of the western stair shall be increased from 1.2 m to 1.7 m to provide sufficient egress for the full occupant loads with the eastern stair being considered unusable if the building is unsprinklered.

Table 5.10: Geometry of rooms as modelled in BRANZFIRE – Bar fire in basement

Room	#	Length (m)	Width (m)		Height (m)	Elevation (m)	Motoring Height (m)
			No SPK	With SPK			
Bar	1	13	7	7	2.5	0.5	2
Foyer	2	11.5	3.2	3.2	3	0	2
Corridor	3	8	1.5	1.5	2.5	0.5	2
West Stair	4	2.6	1.7	1.2	17.5	0.5	16.5
East Stair	5	5.1	4	3	17.5	0.5	16.5

Key: SPK – Sprinkler

Table 5.11 gives the details of vent geometries connecting rooms in BRANZFIRE modelling. No window openings were modelled for the basement level. Widths of doors were adjusted in accordance with standard door size of 860 mm in New Zealand. It shall be noticed that doors with self-closers are taken as half-width for ventilation flow over the time period they are open as specified in the proposed C/VM2. For example, the fire door connecting the bar (Room 1) and western stair (Room 4) shall provide minimum clear width of 1260 mm according to C/AS1, which means it shall be constructed with two door leaves with total width of 1720 mm. As the door is self-closing, only half-width of 860 mm shall be used for ventilation flow. It shall be opened once detector is triggered with open duration based on the queuing time of 56 s if the building is unsprinklered or 60 s if the building is sprinklered.

Table 5.11: Geometry of vents as modelled in BRANZFIRE – Bar fire at basement level

Vent	Width (m)		Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)	
	No SPK	With SPK					No SPK	With SPK
1 to 2	0.86	0.86	2	0	Smoke door	Self-closing	56	60
1 to 4	0.86	0.43	2	0	Fire door	Self-closing	56	60
2 to 3	0.86	0.43	2	0.5	Fire door	Self-closing	89	104
2 to 4	0.86	0.43	2.5	0.5	Fire door	Self-closing	89	104
3 to 5	1.7	1.2	2.5	0	Open wall	Open	Always	

(2) Bar / Dance Floor Fire at Ground Level

Figure 5.11 shows the geometry of the ground level in BRANZFIRE modelling including the bar and dance area, stairway, kitchen, the eastern stair and corridor providing egress to outside. Fire was either located in the bar or dance area. Table 5.12 and Table 5.13 give the details of room and vent geometries in BRANZFIRE modelling for fire at the ground floor. No window openings were modelled considering this type of building use.

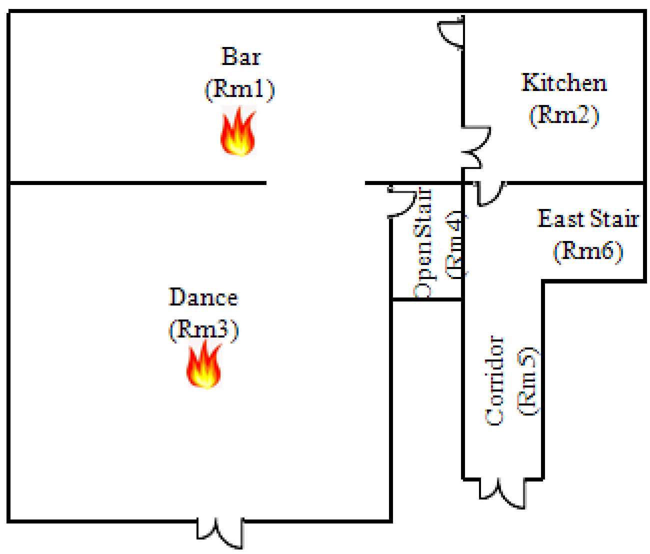


Figure 5.11: Geometry as modelled in BRANZFIRE – Bar / Dance floor fire at ground level

Table 5.12: Geometry of rooms as modelled in BRANZFIRE – Bar/Dance floor fire at ground level

Room	#	Length (m)	Width (m) No SPK	Width (m) With SPK	Height (m)	Elevation (m)	Motoring Height (m)
Bar	1	13	7.3	7.3	2.5	0.5	2
Kitchen	2	7.3	4.5	4.5	2.5	0.5	2
Dance	3	10.4	9.3	9.3	3	0	2
Open Stair	4	4.2	1.2	1.2	5.5	0.5	4.5
Corridor	5	11	2.1	1.6	2.5	0.5	2
East Stair	6	5.1	4	3	14.5	0.5	13.5

Table 5.13: Geometry of vents as modelled in BRANZFIRE – Bar/Dance Fire at ground level

Vent	Width (m) No SPK	Width (m) With SPK	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s) No SPK	Door Open Duration after Detection(s) With SPK
1 to 2	0.86	0.86	2	0	Door	Open	Always	
	1.72	1.72	2	0	Door	Open	Always	
1 to 3	1.8	1.8	2	0	Open wall	Open	Always	
1 to outside	0.02	0.02	2.5	0	Leakage	Open	Always	
2 to 5	0.86	0.43	2	0	Fire door	Self-closing	42	57
2 to outside	0.012	0.012	2.5	0	Leakage	Open	Always	
3 to 4	0.43	0.43	2	0.5	Fire door	Self-closing	Never*	
3 to outside	0.86	0.86	2	0	External door	Self-closing	120	178
	0.01	0.01	3	0	Leakage	Open	Always	
5 to 6	4	3	2.5	0	Stair	Open	Always	
5 to outside	1.29	0.86	2	0	External door	Self-closing	176	281

**The stairway (Room 4) which is not fully enclosed as safe path shall not be counted as egress route according to C/AS1. Hence, the door is modelled as always closed in this exercise but it is modelled as fully open in the performance-based design analysis in the later section.*

(3) Atrium Fire on Floor 2&3

Figure 5.12 shows the geometry of the atrium floors in BRANZFIRE including the bar and atrium space on Floor 2, the upper floor balconies and two staircases providing egress to the ground level. The dotted line shows the wall connecting two rooms is fully open. Table 5.14 and Table 5.15 give the details of room and vent geometries in BRANZFIRE modelling. Floor 4 has to be modified to accommodate a partial reservoir above the atrium area that the ceiling height of the atrium is 9 m.

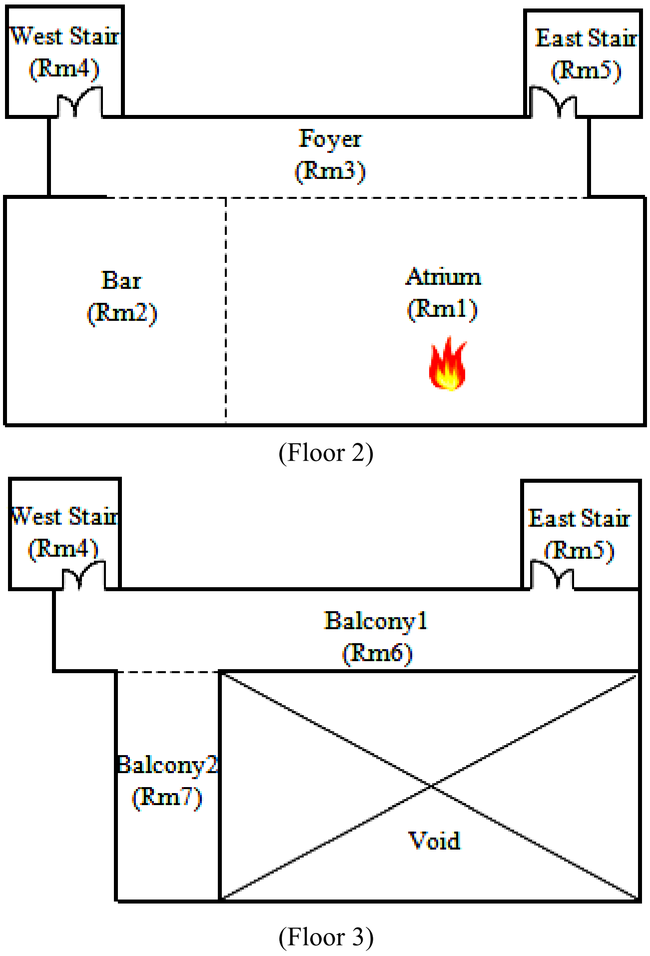


Figure 5.12: Geometry as modelled in BRANZFIRE – Atrium fire on Floor 2&3

Table 5.14: Geometry of rooms as modelled in BRANZFIRE – Atrium fire on Floor 2&3

Room	#	Length (m)	Width (m)		Height (m)	Elevation (m)	Motoring Height (m)
			No SPK	With SPK			
Atrium	1	12.1	7	7	9	0	2
Bar	2	6.7	5.4	5.4	3	0	2
Foyer	3	12.3	2.1	2.1	3	0	2
West Stair	4	4.4	4.5	4	12	0	11
East Stair	5	5.1	4	3	12	0	11
Balcony1	6	16	2.1	2.1	3	3	2
Balcony2	7	7	2.3	2.3	3	3	2

Table 5.15: Geometry of vents as modelled in BRANZFIRE – Atrium fire on Floor 2&3

Vent	Width (m)		Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)	
	No SPK	With SPK					No SPK	With SPK
1 to 2	6.7	6.7	3	0	Open wall	Open	Always	
1 to 3	7.8	7.8	3	0	Open wall	Open	Always	
1 to 6	12.1	12.1	3	3	Open wall	Open	Always	
1 to 7	7	7	3	3	Open wall	Open	Always	
1 to outside	0.02	0.02	9	0	Leakage	Open	Always	
2 to 3	2.3	2.3	3	0	Open wall	Open	Always	
2 to outside	0.012	0.012	3	0	Leakage	Open	Always	
3 to 4	0.86	0.86	2	0	Fire door	Self-closing	68	82
3 to 5	0.86	0.86	2	0	Fire door	Self-closing	68	82
4 to 6	0.86	0.86	2	3	Fire door	Self-closing	39	
4 to outside	0.005	0.004	12	0	Leakage	Open	Always	
5 to 6	0.86	0.86	2	3	Fire door	Self-closing	39	
5 to outside	0.004	0.003	12	0	Leakage	Open	Always	
6 to 7	2.3	2.3	3	0	Open wall	Open	Always	

5.4.1.2 ASET Results

Where the building is unsprinklered, fire is detected by heat detectors at the Basement level & Ground floor, and smoke detectors on Floor 2 & 3 according to previous C/AS1 design in Section 5.3. The simulation was run for 1800 seconds. The BRANZFIRE modelling results are summarised in Table 5.16. The first column shows various fire locations applicable under DFS 1. The second column shows spaces of interest along the escape route from the room of fire origin until occupants away from the firecell of fire origin. The third column shows the detection time either by the activation of heat detectors, or smoke detectors, or sprinklers. Columns 4, 5 & 6 give the time that tenability criteria are reached, including FED CO, FED Thermal and Visibility. The last column summarises the final ASET results for various spaces along the escape routes. The results show that visibility is the first criterion being reached for all fire locations, e.g. for fire in the bar at the basement level. Visibility in the bar (fire origin) drops below 5 m in 54 s before detection, while FED for thermal and CO exceed 0.3 in 162 s and 257 s respectively.

Table 5.16: Summary of BRANZFIRE modelling results for nightclub unsprinklered

Fire Location		Spaces		Detection Time (s)	Time to Reach Tenability Criteria (s) FED CO = 0.3	FED Thermal = 0.3	Visibility = 5 m	ASET (s)
Floor 0	Bar fire	Bar (fire origin)		111 (HD)	257	162	54	54
		Foyer			312	240	106	106
		Corridor			>1800	>1800	123	123
		West Stair			>1800	>1800	108	108
		East Stair			>1800	>1800	198	198
Floor 1	Bar fire	Bar (fire origin)		112 (HD)	285	178	55	55
		Dance floor			407	332	141	141
		Corridor			>1800	>1800	>1800	>1800
		Open Stair			>1800	>1800	>1800	>1800
		East Stair			>1800	>1800	>1800	>1800
	Dance floor fire	Bar		125 (HD)	440	310	128	128
		Dance floor (fire origin)			290	191	78	78
		Corridor			>1800	>1800	>1800	>1800
		Open Stair			>1800	>1800	>1800	>1800
		East Stair			>1800	>1800	>1800	>1800
Floor 2&3	Atrium fire	F2	Atrium (fire origin)	84 (SD)	450	295	246	246
		F2	Foyer		475	353	237	237
		F3	Balcony		502	356	115	115
		West Stair			>1800	>1800	>1800	>1800
		East Stair			>1800	>1800	>1800	>1800

Key: HD – Heat detectors SD – Smoke detectors

Where the building is sprinklered, fire is detected by sprinklers at the Basement level & Ground floor, and smoke detectors on Floor 2 & 3. The BRANZFIRE modelling results are summarised in Table 5.17. Where the building is sprinkler protected, only FED CO applies for occupant tenability as per proposed C/VM2. Results for FED Thermal and CO are also included here for completeness. For example, when fire is located in the bar at the basement level, visibility in the bar (fire origin) drops below 5 m in 55 s before detection, while FED for thermal and CO exceed 0.3 in 155 s and 382 s respectively. However, as only FED CO applies for occupant tenability in sprinkler protected building, the ASET in the bar is 382 s.

Table 5.17: Summary of BRANZFIRE modelling results for nightclub sprinklered

Fire Location		Spaces	Detection Time (s)	Time to Reach Tenability Criteria (s) FED CO = 0.3	FED Thermal = 0.3	Visibility = 5 m	ASET (s)
Floor 0	Bar fire	Bar (fire origin)	126 (SPK)	382	155	55	382
		Foyer		436	328	101	436
		Corridor		>1800	>1800	132	>1800
		West Stair		>1800	>1800	133	>1800
		East Stair		>1800	>1800	192	>1800
Floor 1	Bar fire	Bar (fire origin)	127 (SPK)	465	156	55	465
		Dance floor		600	715	137	600
		Corridor		>1800	>1800	>1800	>1800
		Open Stair		>1800	>1800	>1800	>1800
		East Stair		>1800	>1800	>1800	>1800
	Dance floor fire	Bar	158 (SPK)	540	645	129	540
		Dance floor (fire origin)		408	194	78	408
		Corridor		>1800	>1800	>1800	>1800
		Open Stair		>1800	>1800	>1800	>1800
		East Stair		>1800	>1800	>1800	>1800
Floor 2&3	Atrium fire	F2 Atrium (fire origin)	84 (SD)	991	329	244	991
		F2 Foyer		1077	423	233	1077
		F3 Balcony		1548	454	168	1548
		West Stair		>1800	>1800	>1800	>1800
		East Stair		>1800	>1800	>1800	>1800

Key: SPK – Sprinklers SD – Smoke detectors

5.4.1.3 RSET Result

All occupants are considered to be awake at the time of the fire and, as it is a public building, it is assumed they are unfamiliar with the building layout and possible escape routes. Occupants within the room of fire origin are considered to be able to see, smell or hear fire cues and therefore the expected reaction and response time is faster than those who are away from the fire origin. Hence, occupants in the room of fire origin have pre-movement time of 60 s while occupants in other spaces have pre-movement time of 120 s. Table 5.18 gives the required safe egress time for each fire location for the unsprinklered case. The detection times are taken from BRANZFIRE modelling upon detector activation. For example, when fire is located in the bar at the basement level, heat detector activates in 111 s after ignition. Occupants in the bar start evacuation 60 s after detection. It takes 56 s to clear all occupants from the bar into either foyer space or western staircase, and 89 s to clear all occupants from the basement level. The total required safe egress time to clear the entire building is 339 s.

Table 5.18: RSET results for the nightclub with unsprinklered fire

Events	Time (s)
Fast fire in the Bar on Floor 0 (Basement)	
Time to detection: t_d	111s (Heat detector)
Time for pre-movement: t_p	60s for occupants at basement 120s for occupants in other spaces
Time for travel / flow : t_t	56s clear the Bar (queuing govern) 89s clear the basement (queuing govern) 168s clear entire building (queuing govern)
RSET for clear room of fire origin (Basement bar)	= $t_d + t_p + t_t$ =111s+60s+56s=227s
RSET for clear firecell of fire origin (Basement)	= $t_d + t_p + t_t$ =111s+60s+89s=260s
RSET for clear entire building	= $t_d + t_p + t_t$ =111s+60s+168s=339s
Fast fire in the Bar on Floor 1 (Ground floor)	
Time to detection: t_d	112s (Heat detector)
Time for pre-movement: t_p	60s for occupants on the ground floor 120s for occupants in other spaces
Time for travel / flow : t_t	47s clear the Bar (queuing govern) 120s clear the ground floor (queuing govern) 176s clear entire building (queuing govern)
RSET for clear room of fire origin (Ground bar)	= $t_d + t_p + t_t$ =112s+60s+47s=219s
RSET for clear firecell of fire origin (ground floor)	= $t_d + t_p + t_t$ =112s+60s+120s=292s
RSET for clear entire building	= $t_d + t_p + t_t$ =112s+60s+176s=348s
Fast fire at Dance Floor on Floor 1 (Ground floor)	
Time to detection: t_d	125s (Heat detector)
Time for pre-movement: t_p	60s for occupants on the ground floor 120s for occupants in other spaces
Time for travel / flow : t_t	120s clear the Dance floor via the main entrance (queuing govern) 176s clear entire building (queuing govern)
RSET for clear firecell of fire origin (Ground floor)	= $t_d + t_p + t_t$ =125s+60s+120s=305s
RSET for clear entire building	= $t_d + t_p + t_t$ =125s+60s+176s=361s
Fast fire in the Atrium on Floor 2	
Time to detection: t_d	84s (Smoke detector)
Time for pre-movement: t_p	60s for occupants in the atrium firecell 120s for occupants in other spaces
Time for travel / flow : t_t	68s clear Floor 2 (queuing govern) 39s clear Floor 3 (queuing govern) 169s clear entire building (queuing govern)
RSET for clear floor of fire origin (Floor 2)	= $t_d + t_p + t_t$ =84s+60s+68s=212s
RSET for clear Mezzanine floor (Floor 3)	= $t_d + t_p + t_t$ =84s+60s+39s=183s
RSET for clear entire building	= $t_d + t_p + t_t$ =84s+60s+169s=313s

Table 5.19 summarises the RSET results for building sprinklered. The detection times are based on sprinkler activation on Floor 0 & 1, and smoke detector on the atrium floors.

Table 5.19: RSET results for the nightclub with sprinklered fire

Events	Time (s)
Fast fire in the Bar at Floor 0 (Basement)	
Time to detection: t_d	126s (Sprinkler)
Time for pre-movement: t_p	60s for occupants at basement 120s for occupants in other spaces
Time for travel / flow : t_t	60s clear the Bar (queuing govern) 104s clear the basement (queuing govern) 296s clear entire building (queuing govern)
RSET for clear room of fire origin (bar)	= $t_d+t_p+t_t$=126s+60s+60s=246s
RSET for clear firecell of fire origin (Basement)	= $t_d+t_p+t_t$=126s+60s+104s=290s
RSET for clear entire building	= $t_d+t_p+t_t$=126s+60s+296s=482s
Fast fire in the Bar on Floor 1 (Ground floor)	
Time to detection: t_d	127s (Sprinkler)
Time for pre-movement: t_p	60s for occupants on the ground floor 120s for occupants in other spaces
Time for travel / flow : t_t	60s clear the Bar (queuing govern) 178s clear the ground floor (queuing govern) 281s clear entire building (queuing govern)
RSET for clear room of fire origin (Ground bar)	= $t_d+t_p+t_t$=127s+60s+60s=247s
RSET for clear firecell of fire origin (ground floor)	= $t_d+t_p+t_t$=127s+60s+178s=365s
RSET for clear entire building	= $t_d+t_p+t_t$=127s+60s+281s=468s
Fast fire at Dance Floor on Floor 1 (Ground floor)	
Time to detection: t_d	158s (Sprinkler)
Time for pre-movement: t_p	60s for occupants on the ground floor 120s for occupants in other spaces
Time for travel / flow : t_t	178s clear the Dance floor via the main entrance (queuing govern) 281s clear entire building (queuing govern)
RSET for clear floor of fire origin (Ground floor)	= $t_d+t_p+t_t$=158s+60s+178s=396s
RSET for clear entire building	= $t_d+t_p+t_t$=158s+60s+281s=499s
Fast fire in the Atrium on Floor 2	
Time to detection: t_d	84s (Smoke detector) 291s (Sprinkler)
Time for pre-movement: t_p	60s for occupants in the atrium firecell 120s for occupants in other spaces
Time for travel / flow : t_t	82s clear Floor 2 (queuing govern) 39s clear Floor 3 (queuing govern) 296s clear entire building (queuing govern)
RSET for clear floor of fire origin (Floor 2)	= $t_d+t_p+t_t$=84s+60s+82s=226s
RSET for clear Mezzanine floor (Floor 3)	= $t_d+t_p+t_t$=84s+60s+39s=183s
RSET for clear entire building	= $t_d+t_p+t_t$=84s+60s+296s=440s

5.4.1.4 RSET vs. ASET

Table 5.20 summarises the results for RSET versus ASET and the safety margin for both unsprinkler and sprinkler cases. The design will fail where RSET exceeds ASET. Where the nightclub is unsprinklered, the design shall meet all of the three tenability criteria, whilst only FED CO applies for building sprinklered. Once occupants leave the firecell of fire origin, they are considered temporarily safe. Hence, only results for room and firecell of fire origin are provided here. For unsprinklered case, visibility is the first criteria reached for all fire locations. It drops below 5 m before occupants start evacuation. The design fails to meet C/VM2 criteria if the building is unsrpinklered. For sprinklered case, the results show the design meets C/VM2 criteria. The most critical fire location is for fire in the dance area on the ground floor with safety margin of only 12 s.

Table 5.20: RSET vs. ASET results for the nightclub

		Criteria	Time Reached (s)		Margin = ASET-RSET (s)	
			Unsprinklered	**Sprinklered**	**Unsprinklered**	**Sprinklered**
Basement Bar Fire	Room of fire origin (Bar tenability)					
	RSET(Bar)		227	246	-	-
	ASET	Visibility=5m	54	55	***-173***	***-191*** (N/A)
	ASET	FED Thermal=0.3	162	155	**-65**	**-91** (N/A)
	ASET	FED CO=0.3	257	382	30	136
	Firecell of fire origin (Foyer tenability)					
	RSET(Basement)		260	290	-	-
	ASET	Visibility=5m	106	101	***-154***	***-189*** (N/A)
	ASET	FED Thermal=0.3	240	328	***-20***	38 (N/A)
	ASET	FED CO=0.3	312	436	52	146
Ground Floor Bar Fire	Room of fire origin (Bar tenability)					
	RSET(Bar)		219	247	-	-
	ASET	Visibility=5m	55	55	***-164***	***-192*** (N/A)
	ASET	FED Thermal=0.3	178	156	**-41**	**-91** (N/A)
	ASET	FED CO=0.3	285	465	66	218
	Firecell of fire origin (Dance floor tenability)					
	RSET(Main Exit)		292	365	-	-
	ASET	Visibility=5m	141	137	***-151***	***-228*** (N/A)
	ASET	FED Thermal=0.3	332	715	40	350 (N/A)
	ASET	FED CO=0.3	407	600	115	235
Ground Floor Dance Fire	Firecell of fire origin (Dance Floor tenability)					
	RSET(Main Exit)		305	396	-	-
	ASET	Visibility=5m	78	78	***-227***	***-318*** (N/A)
	ASET	FED Thermal=0.3	191	194	***-114***	***-202*** (N/A)
	ASET	FED CO=0.3	290	408	***-15***	12

(Continuous…)

	Criteria		Time Reached (s)		Margin = ASET-RSET (s)	
			Unsprinklered	Sprinklered	Unsprinklered	Sprinklered
Floor 2 Atrium Fire	Firecell of fire origin on Floor 2					
	RSET(Floor 2)		212	226	-	-
	ASET	Visibility=5m	237	233	25	7 (N/A)
		FED Thermal=0.3	353	423	141	197 (N/A)
		FED CO=0.3	475	1077	263	851
	Firecell of fire origin on Floor 3					
	RSET(Floor 3)		183	183	-	-
	ASET	Visibility=5m	115	168	***-68***	***-15*** (N/A)
		FED Thermal=0.3	356	454	173	271 (N/A)
		FED CO=0.3	502	1548	319	1365

Values shown in ***bold italic*** *show that RSET exceeds the ASET* N/A – Not applicable

5.4.2 DFS 2 – Blocked Exit

This fire scenario is concerned with the location of the fire physically obstructing an exit. It would not allow a single escape route serving more than 50 occupants for an open path or horizontal safe path; or a vertical safe path serving more than 150 occupants (or 250 if the building is sprinkler protected).

Except that some rooms with occupant loads up to 50 are allowed to have single escape routes from room origin, all other spaces with over 50 occupants have at least two means of escape. Both egress routes shall be similarly sized so that with one blocked exit in each space still have at least 50 % of the required exit width available.

There are concerns for the Bar at the basement level which have two means of escape with widths of 1.1 m and 1.8 m respectively. With the 1.8m exit blocked the RSET will increase from 246 s to 359 s for the sprinklered case. The ASET (FED CO) for fire in the Bar is 382 s that this scenario is still achieved but with a safety margin reduced to 23 s. Therefore, designers shall demonstrate that where two egress routes are not equally sized, the one with minimum width shall still be able to provide capacity for at least 50 % of the full occupant loads.

5.4.3 DFS 3 – Fire in Unoccupied Room

The building contains unoccupied rooms, e.g. storage, housekeeping, back stages etc. The fire safety precautions for this building include a fully compliant sprinkler system or detection system installed throughout the building. Therefore, this scenario is achieved.

5.4.4 DFS 4 – Fire in Concealed Space

The fire safety precautions for this building include a fully compliant sprinkler system or detection system installed throughout the building. Therefore, this scenario is achieved.

5.4.5 DFS 5 – Smouldering Fire

This scenario aims to protect sleeping occupants. There is no requirement to test this scenario in the nightclub where there is no sleeping use. Therefore, this scenario is satisfied.

5.4.6 DFS 6 – Fire Spread to Other Property

There is no adjacent property therefore this scenario is not applicable.

5.4.7 DFS 7 – Vertical External Fire Spread

The building does not have sleeping occupants on upper floors and the building height is less than 10 m. Therefore, this scenario is not applicable.

5.4.8 DFS 8 – Interior Surface Finishes

This scenario applies to all buildings except that a smoke production rate criterion is not required for sprinkler protected buildings. Criteria need not be applied to small areas of product within a firecell less than 5 m^2 or 5 % of floor area whichever is greater.

In order to achieve DFS 8, wall, ceiling and floor materials must meet the following criteria:

- Wall/ceiling materials in exitways, assembly/crowd spaces and floor surfaces in vertical safe paths shall be no less than Group 2 materials in accordance with ISO 9705. That is, the time to flashover (under test conditions of ISO 9705) not less than 10 minutes.
- All other locations the wall and ceiling materials shall be no less than Group 3 materials in accordance with ISO 9705. That is, the time to flashover (under test conditions of ISO 9705) not less than 2 minutes.
- Floor surfaces in horizontal safe paths, assembly/crowd purpose groups shall meet floor radiant panel criteria.

5.4.9 DFS 9 – Fire Service Operations

The objective of this scenario is to make a risk-informed judgement about how to tackle firefighting and rescue operations. Analysis for firefighter tenability is required for FHC 4 buildings over 1500 m^2 or unsprinklered buildings where the distance from the safe path access to any point on a floor exceeds 75 m. Therefore, firefighting tenability is not applicable as the nightclub building is either fully sprinklered in accordance with *NZS 4541* or safe path access is within 75 m. However, the following criteria shall still be achieved:

- To facilitate rapid size-up of the situation for firefighting, control panels indicating the status of fire safety systems will be installed in the building;

- To facilitate safe access for rescue and firefighting, there is no point on a floor that is further than 75 m from a safe path access for firefighters. Structural stability criteria for firefighters are achieved by providing fire resistance ratings;
- To facilitate adequate firefighting water, internal hydrant system is provided in accordance with *NZS 4510:2008 Fire Hydrant Systems for Buildings*[61] and the building is fully sprinkler protected.

5.4.10 DFS 10 – Robustness Check

The objective of this scenario is to do a robustness check with each key fire safety system rendered in effective in turn, including smoke management systems, and fire and/or smoke doors. Fire sprinklers and automatic fire alarms complied with New Zealand Standard are considered to be sufficiently reliable to achieve DFS 10.

5.4.10.1 Smoke Control System

As the building has smoke control system over the atrium space and failure of the smoke exhaust may expose more than 150 occupants to untenable conditions, detailed tenability analysis is required under this scenario. The assessment was carried out for fire in the atrium on Floor 2 without smoke exhaust and the building is sprinklered. Only FED CO applies for tenability criteria. The results are summarised in Table 5.21.

The results show that the sprinkler activates at 274 s and controls the fire at 3528 kW. FED CO exceeds 0.3 at 636 s on Floor 3 while all occupants have cleared from the building. Therefore, the design still meets the performance criteria without smoke control system over the atrium space. It also means, to meet C/VM2 criteria, smoke control system may not required for a performance-based design even though it is required in a C/AS1 design.

Table 5.21: RSET vs. ASET for fire in the Atrium on Floor 2 without smoke exhaust system

Criteria		Time Reached (s)	Margin = ASET-RSET (s)
Firecell of fire origin on Floor 2			
RSET(Floor 2)		226	-
ASET	Visibility=5m	155	***-71*** (N/A)
	FED Thermal=0.3	341	115 (N/A)
	FED CO=0.3	641	415
Firecell of fire origin on Floor 3			
RSET(Floor 3)		183	-
ASET	Visibility=5m	149	***-34*** (N/A)
	FED Thermal=0.3	341	158 (N/A)
	FED CO=0.3	636	453

*Values shown in **bold italic** show that RSET exceeds the ASET N/A – Not applicable*

5.4.10.2 Fire / Smoke Doors

It is rare that all fire doors in a building are failed to remain their normal function at the same time. For this scenario, each fire door is rendered ineffective in turn. With one safe path staircase becomes untenable, the building still has alternative safe path for egress. The ASET versus RSET analysis was carried out for fire in the bar at the basement level with the fire door into the western staircase rendered ineffective (modelled as open) as shown in Figure 5.13. The results show that the FED CO of the western staircase reaches 0.3 at 415 s while occupants at the basement have cleared from this level at 290 s. The design still meets the criteria.

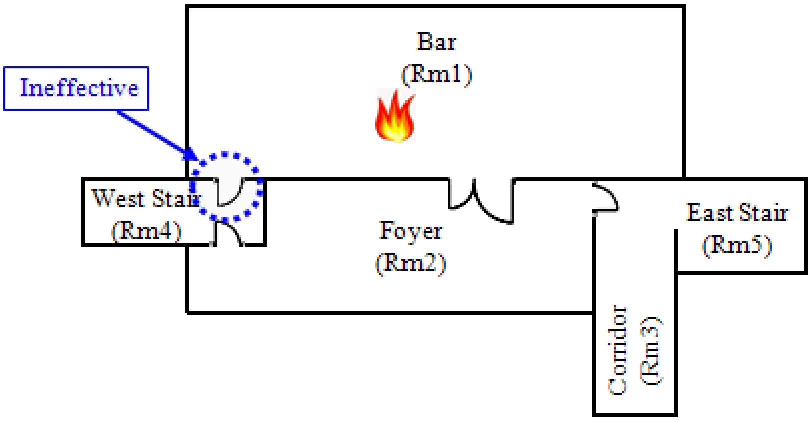


Figure 5.13:Fire door into west staircase at basement rendered ineffective

5.5 Summary of Safety Margin for DFS 1

This section provides a summary of the safety margins that the C/AS1 compliant nightclub can achieve under the C/VM2 principles for DFS 1. For designs without sprinklers, results of all three detailed criteria including visibility, FED thermal and FED CO are provided here. While sprinklers are installed, only FED CO is provided. To meet the current framework, the design shall achieve a minimum safety factor of 1.0. Readers shall be aware that:

Safety Margin = ASET – RSET (9.1)

Safety Factor (SF) = ASET / RSET (9.2)

5.5.1 Without sprinkler system

Figure 5.14 and Figure 5.15 summarise the achieved safety margins of the unsprinklered case for the room and firecell of fire origin respectively. The light green bars show the RSET results, and the dark green bars show the achieved safety margin, i.e. for fire located in the bar at the basement level, the RSET to clear the bar (fire origin) is 227 s. The achieved safety margin for FED CO is 30 s with safety factor of 1.1, while the margin for FED Thermal is -65 s with achieved safety factor of 0.7 and the margin for Visibility is -173 s with achieved safety factor of 0.2. The design therefore fails to comply with C/VM2. The only solution to meet the proposed C/VM2 criteria is to provide sprinklers throughout the nightclub building.

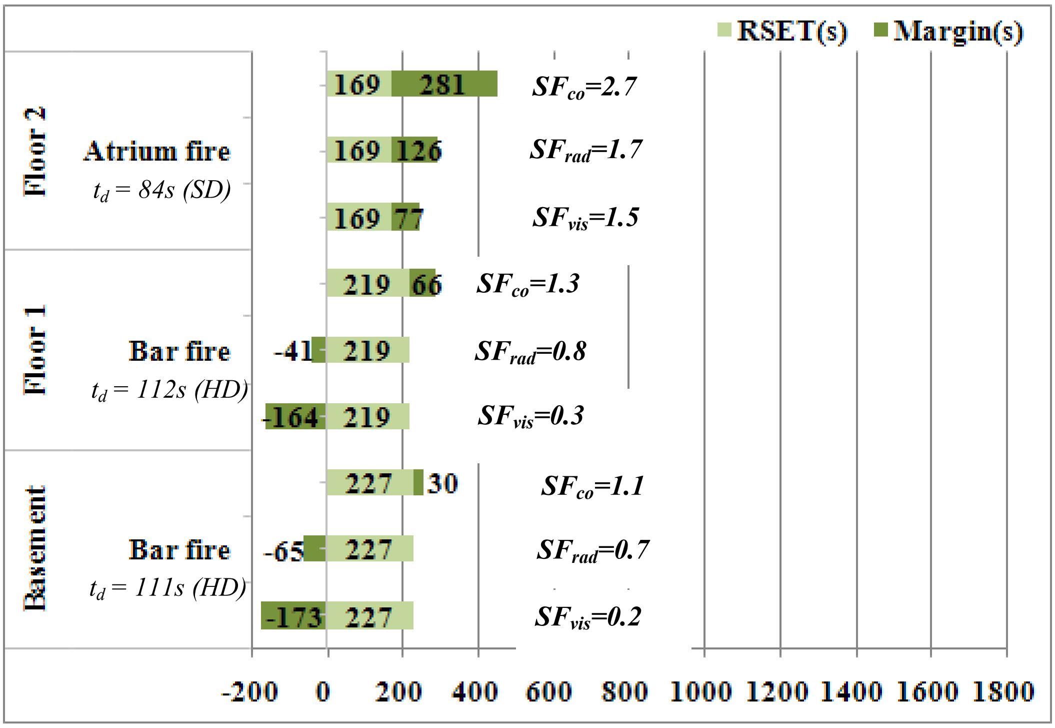


Figure 5.14: Nightclub (unsprinklered) safety margin for room of fire origin

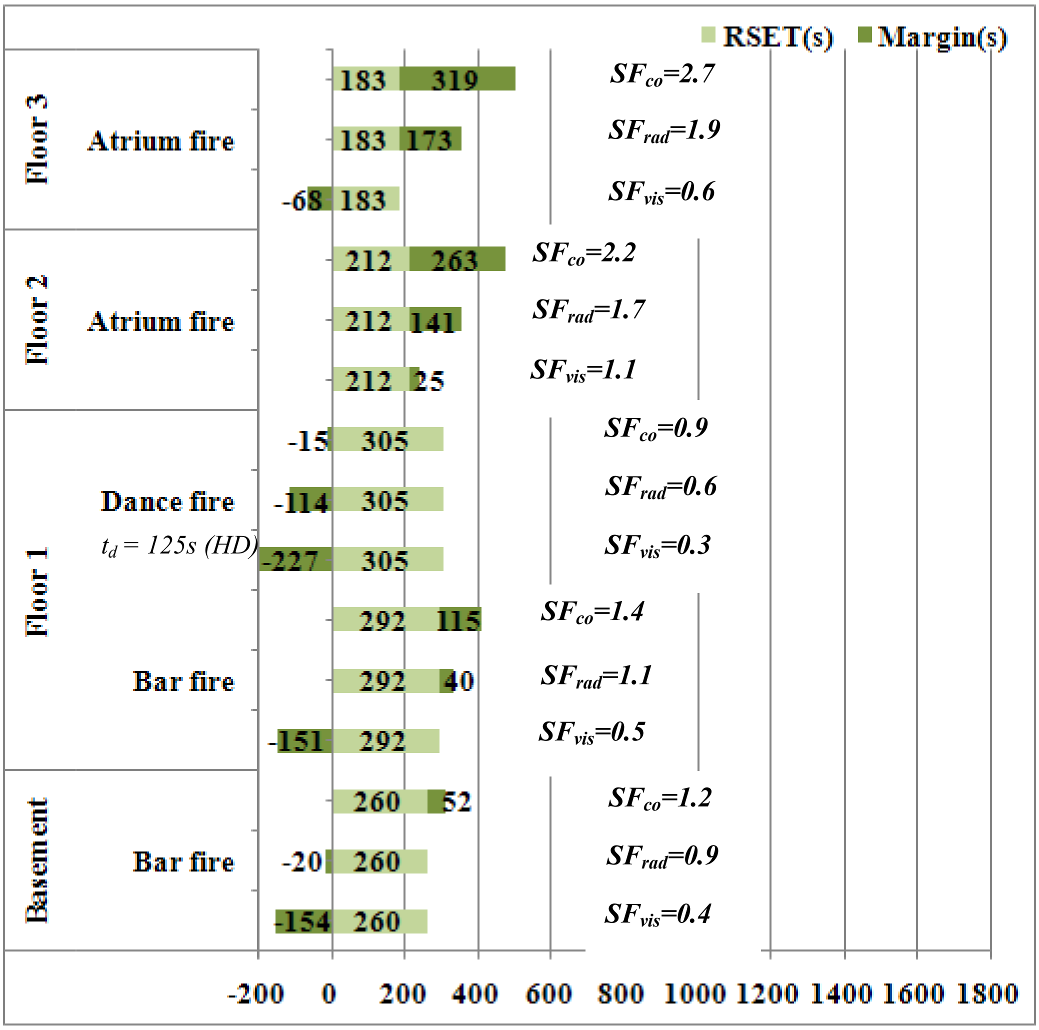


Figure 5.15: Nightclub (unsprinklered) safety margin for firecell of fire origin

5.5.2 With sprinkler system

Fire protection systems include sprinklers throughout the building, smoke detectors and smoke control system on Floor 2 & 3. Widths of egress routes are not increased but open stairways shall be closed off and basement stairs shall provide egress directly to outside. As shown in Figure 5.16 and Figure 5.17, the design with sprinkler system meets C/VM2 criteria with safety factor of 1.0. The most critical fire location is at Dance Floor on the ground floor with a safety margin of 12 s.

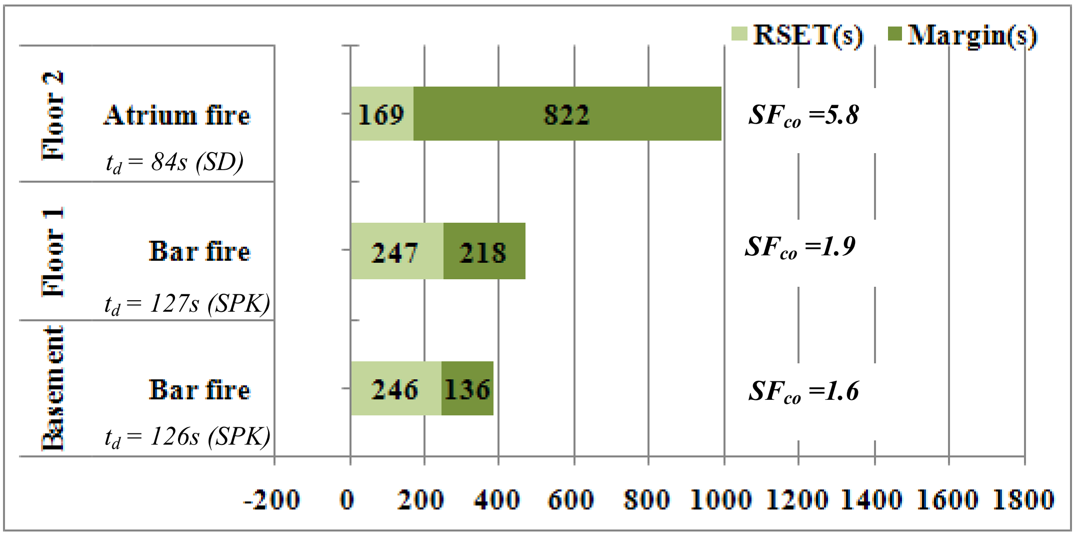


Figure 5.16: Nightclub (sprinklered) safety margin for room of fire origin

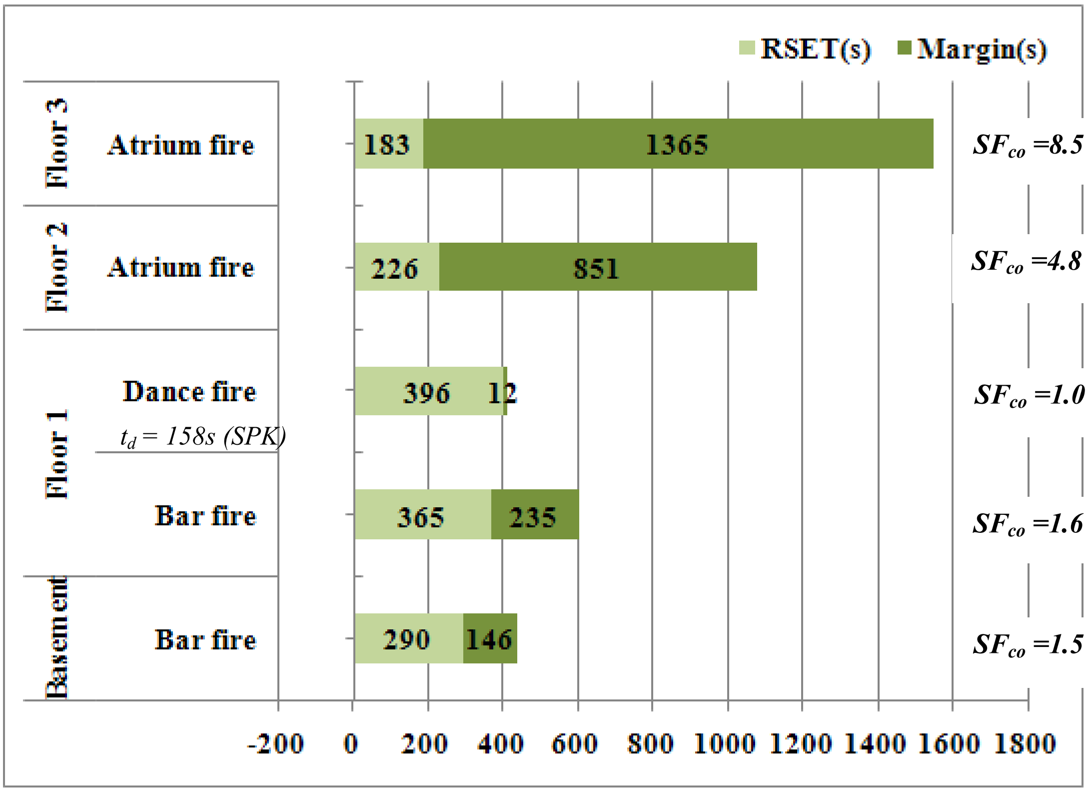


Figure 5.17: Nightclub (sprinklered) safety margin for firecell of fire origin

5.6 Discussion

Based on the above analysis, the design fire specified in C/VM2 is very severe that visibility drops too quickly in room of fire origin. For relative small space less than 100 m^2, visibility often drops below 5 m before occupants start evacuation. This will force designers to provide sprinkler systems in the design so that visibility is exempted from the performance criteria.

On the other hand, the proposed C/VM2 has relaxed criteria for buildings with sprinkler system: firstly, only FED CO applies for performance criteria that visibility and FED Thermal are not required to be assessed; secondly, robustness check does not apply to sprinkler systems which are considered sufficiently reliable. The suggestion is to increase the safety factor to be achieved for FED CO where the building is sprinklered.

DFS 1 requires the most analysis in a performance-based design under C/VM2. Readers may notice that the dance area by the main entrance originally has less than 150 occupants and has a floor area less than 200 m^2 which is not applicable under DFS 1. However, it becomes the most critical fire location as occupants from other spaces will egress through the dance floor and out of the building via the main entrance. Therefore, it is suggested that DFS 1 shall be revised to apply for any room / space serving more than 150 occupants as well as providing supporting activities to those occupants. (It does not apply to spaces, e.g. corridors and stairs, serving more than 150 occupants but not providing functional activity to those occupants.)

5.7 Performance-Based Design

5.7.1 Introduction

Previous sections provide the prescriptive solutions and analysis results using proposed C/VM2 principles for the nightclub building. In this section, performance-based design is carried out for the same nightclub building. The objective is to provide a fire safety alternative with as little change to the building fabric and egress system as possible. Several alternatives are discussed here starting from the minimum required fire protections.

The alternative designs will follow the proposed C/VM2 that typically DFS 1 is the most challenging part which requires detailed analysis for the Available Safe Egress Time (ASET) versus Required Safe Egress Time (RSET) for any room that is larger than 200 m^2 or has more than 150 occupants. BRANZFIRE modelling was used for the analysis. The other scenarios which require less sophisticated analysis and similar to those discussed in previous sections will not be further addressed here.

Based on the previous analysis results in Section 5.5, the nightclub building must be sprinkler protected to meet the C/VM2 criteria as the minimum requirement. According to the discussion in the last section, it is suggested to increase the safety factor for FED CO where the building is sprinklered. Hence, the results for designs to achieve a safety factor of 1.5 and 2.0 are included here as references.

For all trial designs,

- Smoke control system is not provided over the atrium space on Floor 2 & 3, even though it is required in the prescriptive design;
- Two staircases, the western staircase providing access from ground floor to upper floors and the eastern staircase providing access for all levels, are fully enclosed as safe paths. However, the open stairways at basement and ground floor remain open, and occupants are allowed to egress through them (they are not allowed to be counted as egress routes in the prescriptive solutions), e.g. part of the occupants at basement will egress through the western open stairway and out of the building via the main entrance; part of the occupants on Floor 2 will egress through the open stairway (adjacent to the wardrobe) to the ground floor and out of the building via the main entrance. Therefore, a longer RSET to clear the ground floor is expected than that of a C/AS1 compliant design.

5.7.2 DFS 1 – Trial Design 1

The building is protected by standard response sprinklers (RTI = 95) throughout, and with no modification to the egress system even though it is considered not sufficient for this building type. The ASET & RSET calculations followed the same procedures as discussed in previous sections. The RSET versus ASET results for clear room / firecell of fire origin are summarised in Figure 5.18 and Figure 5.19 respectively. As the building is sprinker protected, only results for FED CO are provided here for occupant tenability. The results show that the design does not achieve a safety factor of 1.0 for FED CO. The most critical fire location is at the Dance Floor on the ground floor with achieved safety factor of 0.9. For the later trial designs, fire is only modelled at the ground floor bar and Dance area.

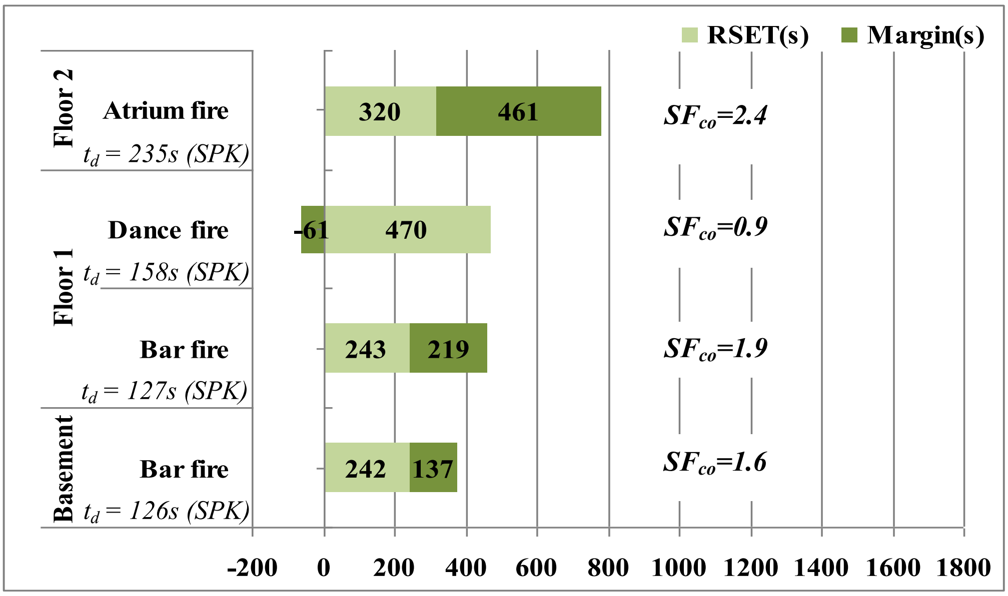


Figure 5.18: RSET vs. ASET results for Trial Design 1 – room of fire origin

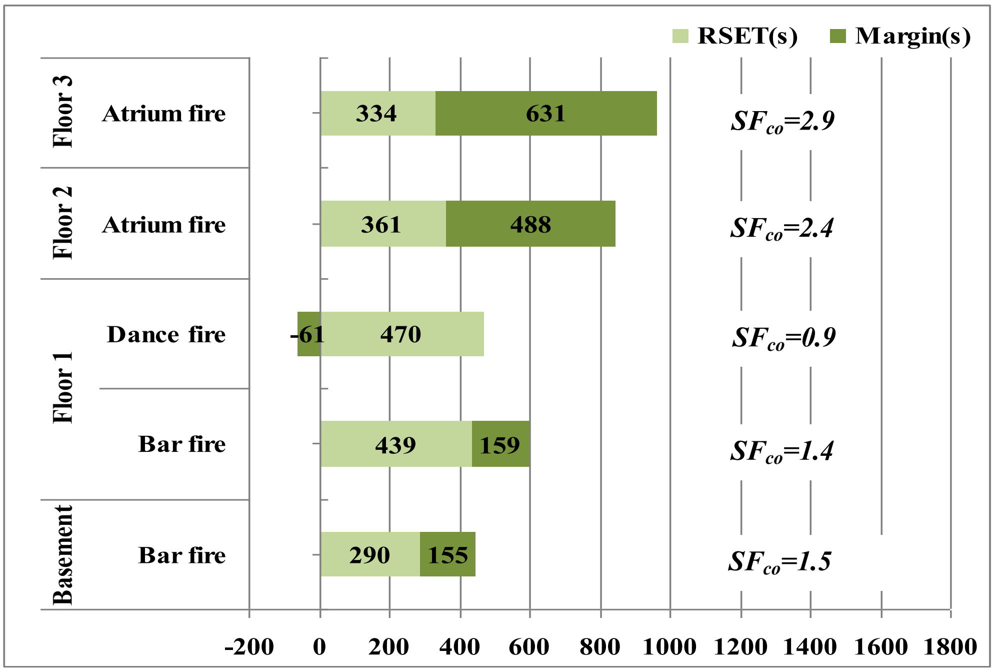


Figure 5.19: RSET vs. ASET results for Trial Design 1 – firecell of fire origin

5.7.3 DFS 1 – Trial Design 2

The building is protected by fast response sprinklers (RTI = 36) throughout with no modification to the egress system. The RSET versus ASET results for clear room / firecell of fire origin are summarised in Figure 5.20 and Figure 5.21 for fire at the Bar or Dance on the ground floor. The results show that the design can just achieve a safety factor of 1.1 for fire at the Dance floor.

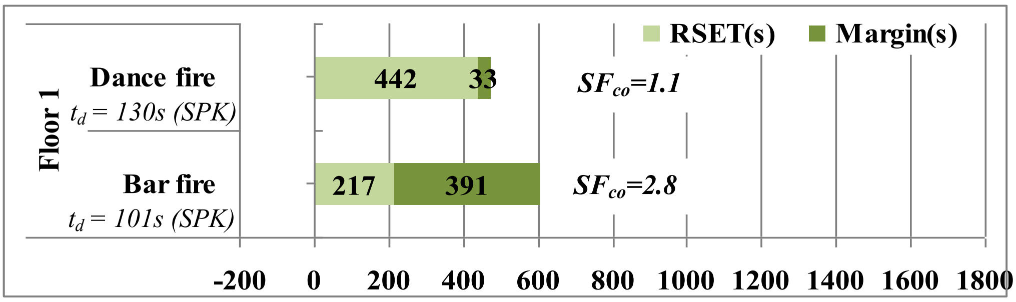


Figure 5.20: RSET vs. ASET results for Trial Design 2 – room of fire origin

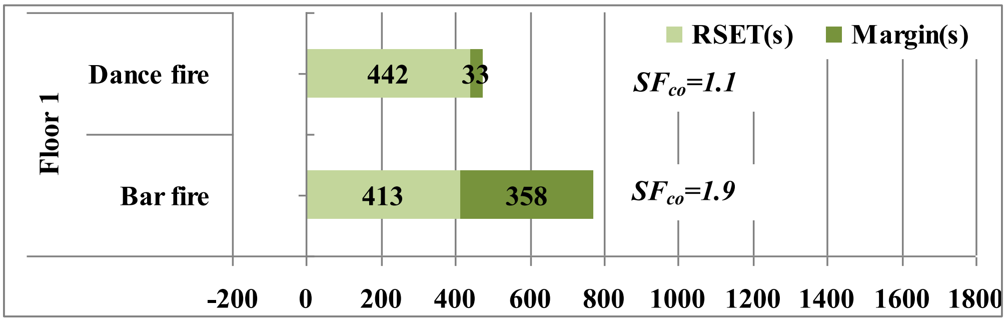


Figure 5.21: RSET vs. ASET results for Trial Design 2 – firecell of fire origin

5.7.4 DFS 1 – Trial Design 3

The building is protected by standard response sprinklers (RTI = 95) throughout, and widths of egress routes need to be increased. Based on analysis in Trial design 1, the egress time to clear the basement to the ground floor is 385 s after ignition for fire at the Dance Floor. Tenability condition for FED CO of 0.3 is reached at 409 s after ignition at the Dance Floor. Therefore, only increase the width of the main entrance is not a solution to achieve safety factor of 2.0. The following analysis is carried out for fire at the ground level Dance:

(1) To achieve safety factor of 2.0

As shown in Table 5.22, given the ASET for FED CO is 409 s, to achieve a safety factor of 2.0, occupants shall be cleared from main entrance in 204 s after ignition. As the detection time for standard response sprinkler is 158 s and pre-movement time for occupants on the ground floor is 60 s, a safety factor of 2.0 cannot be achieved unless smoke detectors are installed for early warning.

Table 5.22: Required flow time to achieve SF=2 for fire at Dance on Floor 1 – Trial Design 3

ASET (FED CO)	409 s
RSET shall be	204 s
Detection time (STD SPK)	158 s
$t_{pre\text{-}movement}$ of fire origin	60 s
$t_{pre\text{-}movement}$ of basement	120 s
Required t_{flow} of clear ground floor to outside via main entrance	-14 s
Required t_{flow} of clear basement to outside via main entrance	-74 s

(2) To achieve safety factor of 1.5

As shown in Table 5.23, it is impossible to achieve safety factor of 1.5 if occupants at basement egress through the main entrance. The required flow time to clear ground floor to outside via the main entrance is 54 s. Hence, to achieve a safety factor of 1.5, it is required:

- Occupants at basement shall not egress through the main entrance via the dance area but only via the eastern safe path staircase (hard to be achieved). Or, enclose western open stairway at basement and provide egress directly to outside as required by C/AS1; and
- Egress routes to outside on the ground floor shall provide total effective width no less than 4.52 m based on the calculations. Considering a single NZ standard door leaf of 0.86 m, width of egress via main entrance and eastern corridor shall increase to 3.44 m (equivalent to 2 double doors of total 4 door leaves) respectively.

Table 5.23: Required flow time to achieve SF=1.5 for fire at Dance on Floor 1 – Trial Design 3

ASET (FED CO)	409 s
RSET shall be	272 s
Detection time (STD SPK)	158 s
$t_{pre\text{-}movement}$ of fire origin	60 s
$t_{pre\text{-}movement}$ of basement	120 s
Required t_{flow} of clear ground floor to outside via main entrance	54 s
Required t_{flow} of clear basement to outside via main entrance	-6 s

(3) To achieve safety factor of 1.0

As shown in Table 5.24, the required flow time to clear ground floor to outside via the main entrance is 191 s, and 131s to clear basement. To achieve safety factor of 1.0, egress routes on the ground floor shall provide total effective width no less than 2.03 m based on the calculations. Considering a single NZ standard door leaf of 0.86 m, width of the main entrance shall increase to 1.72 m (equivalent to one double door of 2 door leaves) and eastern corridor shall increase to 1.72 m (equivalent to one double door of 2 door leaves).

Table 5.24: Required flow time to achieve SF=1.0 for fire at Dance on Floor 1 – Trial Design 3

ASET (FED CO)	409 s
RSET shall be	409 s
Detection time (STD SPK)	158 s
$t_{pre\text{-}movement}$ of fire origin	60 s
$t_{pre\text{-}movement}$ of basement	120 s
Required t_{flow} of clear ground floor to outside via main entrance	191 s
Required t_{flow} of clear basement to outside via main entrance	131 s

5.7.5 DFS 1 – Trial Design 4

The building is protected by standard response sprinklers (RTI = 95) throughout and smoke detectors are provided at basement and ground floor, and without any egress modification. The RSET versus ASET results for clear room / firecell of fire origin are summarised in Figure 5.22 and Figure 5.23 respectively. The results show that the design can just achieve a safety factor of 1.1.

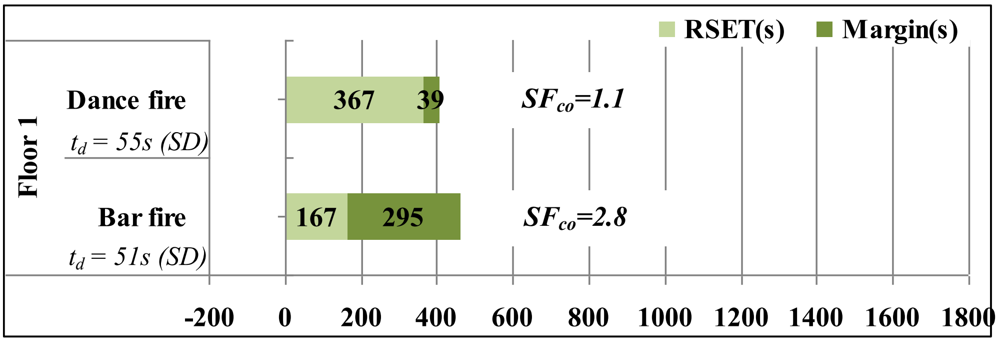


Figure 5.22: RSET vs. ASET results for Trial Design 4 – room of fire origin

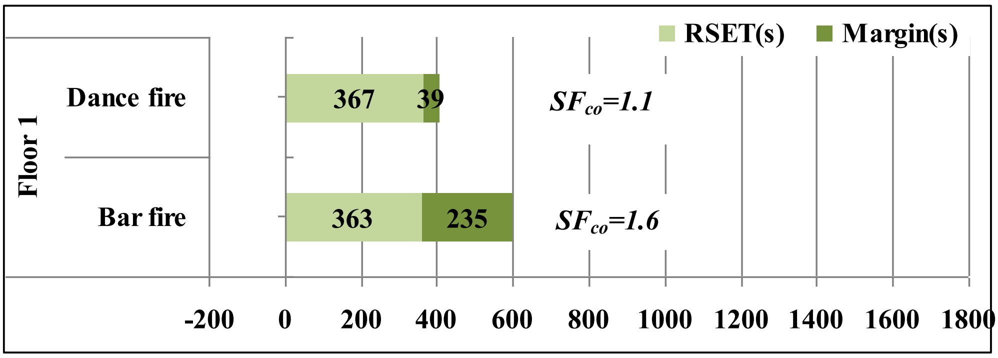


Figure 5.23: RSET vs. ASET results for Trial Design 4 – firecell of fire origin

5.7.6 DFS 1 – Trial Design 5

Same as Trail Design 4, the building is protected by standard response sprinklers (RTI = 95) throughout and smoke detectors are provided at basement and ground floor for early warning. Meanwhile, widths of egress routes need to be increased to achieve a safety factor greater than 1.0.

(1) To achieve safety factor of 2.0

As shown in Table 5.25, it is impossible to clear basement to outside via the main entrance within 29 s after pre-movement. Hence, the only solution is to:

- Enclose western open stairway at basement and provide egress directly to outside as required by C/AS1; and
- Egress routes to outside on the ground floor shall provide total effective width no less than 3.16 m based on the calculations. Considering a single NZ standard door leaf of 0.86 m, width of the main entrance shall increase to 2.58 m (equivalent to 3 door leaves) and eastern corridor shall increase to 1.72 m (equivalent to 2 door leaves).

Table 5.25: Required flow time to achieve SF=2.0 for fire at Dance on Floor 1 – Trial Design 5

ASET (FED CO)	409 s
RSET shall be	204 s
Detection time (STD SPK)	55 s
$t_{pre\text{-}movement}$ of fire origin	60 s
$t_{pre\text{-}movement}$ of basement	120 s
Required t_{flow} of clear ground floor to outside via main entrance	89 s
Required t_{flow} of clear basement to outside via main entrance	29 s

(2) To achieve safety factor of 1.5

As shown in Table 5.26, the required flow time to clear ground floor to outside via the main entrance is 157 s and 97 s to clear basement. To achieve safety factor of 1.5, egress routes on the ground floor shall provide total effective width no less than 2.31 m based on the calculations. Considering a single NZ standard door leaf of 0.86 m, width of the main entrance and eastern corridor shall increase to 1.72 m (equivalent to 2 door leaves) respectively. Egress providing access to eastern staircase at basement shall provide effective width no less than 1.13 m based on the calculations, which is equivalent to 1.72 m doorway of 2 door leaves.

Table 5.26: Required flow time to achieve SF=1.5 for fire at Dance on Floor 1 – Trial Design 5

ASET (FED CO)	409 s
RSET shall be	272 s
Detection time (STD SPK)	55 s
$t_{pre\text{-}movement}$ of fire origin	60 s
$t_{pre\text{-}movement}$ of basement	120 s
Required t_{flow} of clear ground floor to outside via main entrance	157 s
Required t_{flow} of clear basement to outside via main entrance	97 s

5.7.7 DFS 1 – Trial Design 6

Same as Trail Design 2, the building is protected by fast response sprinklers (RTI = 36) throughout. To achieve a safety factor greater than 1.0, widths of egress routes need to be increased as discussed below for fire at the Dance Floor.

(1) To achieve safety factor of 2.0

As shown in Table 5.27, it is impossible to achieve safety factor of 2.0 if occupants at basement egress through the main entrance. Hence, the only solution is to:

- Enclose western open stairway at basement and provide egress directly to outside as required by C/AS1; and

- Egress routes to outside on the ground floor shall provide total effective width no less than 5.7 m based on the egress calculations. Considering a single NZ standard door leaf of 0.86 m, width of the main entrance and eastern corridor shall increase to 3.44 m (equivalent to 4 door leaves) respectively.

Table 5.27: Required flow time to achieve SF=2.0 for fire at Dance on Floor 1 – Trial Design 6

ASET (FED CO)	475 s
RSET shall be	237 s
Detection time (STD SPK)	130 s
$t_{pre\text{-}movement}$ of fire origin	60 s
$t_{pre\text{-}movement}$ of basement	120 s
Required t_{flow} of clear ground floor to outside via main entrance	47 s
Required t_{flow} of clear basement to outside via main entrance	-13 s

(2) To achieve safety factor of 1.5

As shown in Table 5.28, the required flow time to clear ground floor via the main entrance is 175 s and 115 s to clear basement. To achieve safety factor of 1.5, egress routes on the ground floor shall provide total effective width no less than 2.16 m. Considering a single standard door leaf of 0.86 m, width of the main entrance and eastern corridor shall increase to 1.72 m (equivalent to 2 door leaves) respectively.

Table 5.28: Required flow time to achieve SF=2.0 for fire at Dance on Floor 1 – Trial Design 6

ASET (FED CO)	475 s
RSET shall be	365 s
Detection time (STD SPK)	130 s
$t_{pre\text{-}movement}$ of fire origin	60 s
$t_{pre\text{-}movement}$ of basement	120 s
Required t_{flow} of clear ground floor to outside via main entrance	175 s
Required t_{flow} of clear basement to outside via main entrance	115 s

5.7.8 Summary of Design Results

Table 5.29 provides a summary of results for the performance-based design including total of six trial designs and its achieved safety factors. The building does not meet the current C/VM2 if it is protected with standard sprinklers only but without any devices for early detection or modification on the egress system. To achieve a safety factor of 1.0, the building requires fast response sprinklers to provide early warning as well as control the fire if it is not desirable to modify the current egress. Egress system needs to be modified if standard response sprinklers are used to achieve a safety factor of 1.0 or 1.5. To achieve a higher safety factor of 2.0, it is recommended to provide smoke detectors for early detection as well as increase width of egress routes where most congestion occurs, e.g. the main entrance, stairways and corridor on the ground floor.

Table 5.29: Summary results of PBD for the nightclub

Trial Design	Design Features					Achieved SF		
	SD	SPK		Safe Path Staircases	Increase Width of Egress	1.0	1.5	2.0
		STD Response	Fast Response					
1	-	√	-	√	-	F	F	F
2	-	-	√	√	-	**P**	F	F
3	-	√	-	√	√	**P**	**P**	F
4	√	√	-	√	-	**P**	F	F
5	√	√	-	√	√	**P**	**P**	**P**
6	-	-	√	√	√	**P**	**P**	**P**

*Key: F – Fail **P** – Pass STD – Standard SF – Safety factor*

5.8 FDS vs. BRANZFIRE

Fire Dynamic Simulator (FDS) has been used to evaluate the appropriateness of BRANZFIRE modelling on complex buildings. The graphic layout of the nightclub building in Smokeview is shown in Figure 5.24. Two fire locations were selected for simulations which are considered as the 'worst-case' fire locations in terms of smoke movement and crowded occupancy causing congestion in evacuation, including the basement bar fire and the ground level dance fire. Inputs for design fire parameters and construction materials are consistent with those in BRANZFIRE modelling. A grid size of 200 mm was used in the simulation.

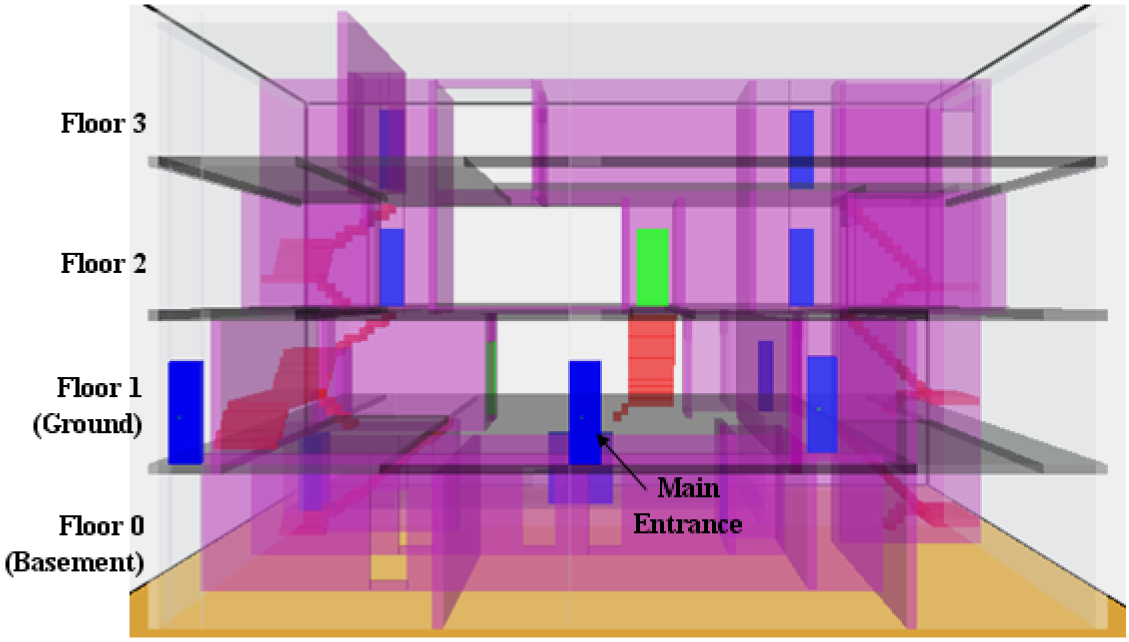
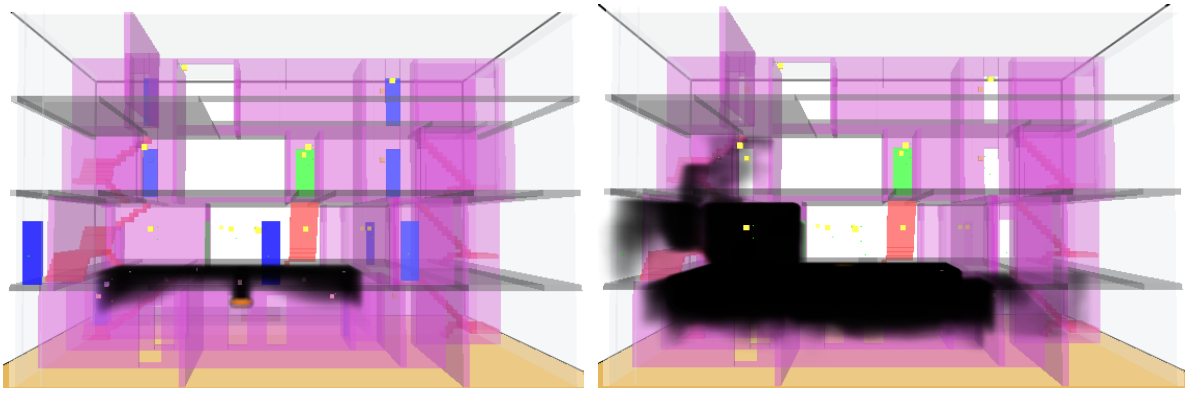


Figure 5.24: Nightclub building layout in FDS shown in Smokeview

5.8.1 Basement Bar Fire (C/AS1 Compliant Design)

In this case, fire is located at the basement bar and capped by sprinkler activation. The building is C/AS1 compliant that the western staircase is enclosed as a safe path. Devices are located mid-points from the fire to boundary walls in the room of fire origin or nearby exits as attached in APPENDIX L-1 as well as results at each location.

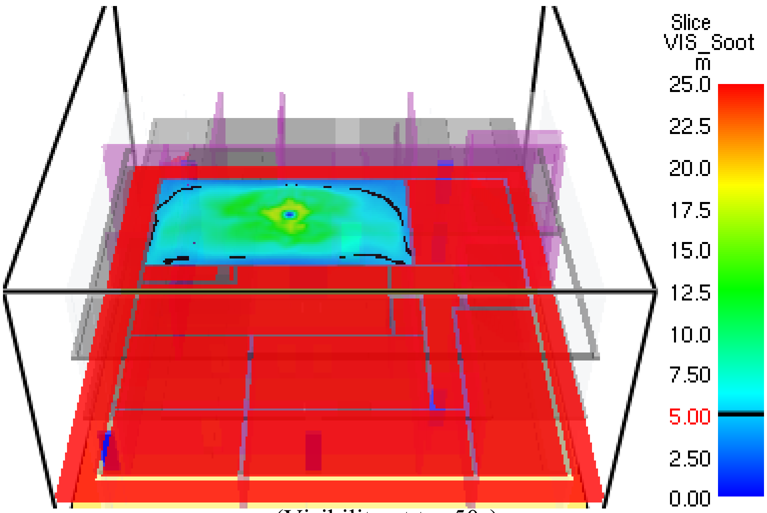
Figure 5.25 shows the smoke development at t = 50 s & 150 s (elevation view from the south). Once egress doors (e.g. door connecting the bar & foyer) open for evacuation, smoke starts filling into the foyer and staircases, even they are smoke/fire separated as protected/safe paths. This is consistent with BRANZFIRE results that visibility drops below 5 m at 101 s in the foyer and 133 s in the western stair.



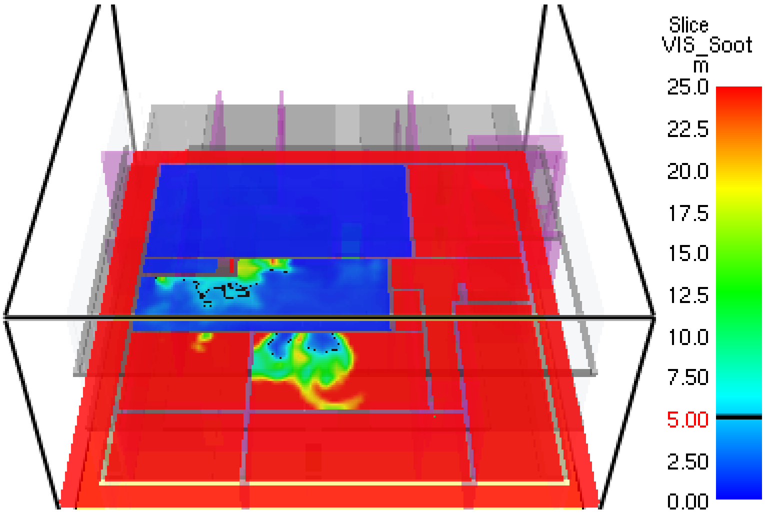
(Elevation view at t = 50s) (Elevation view at t = 150s)

Figure 5.25: Smoke development in FDS for basement bar fire

Figure 5.26 and Figure 5.27 show the visibility and temperature 'slices' 2 m above the basement floor level at t = 50 s & 150 s. During the early stage of fire development, the plume flow impinges on the ceiling and spreads across as a circular jet until eventually reaches the walls and move downward along the wall. Hence, it can be seen the visibility drops below 5 m quickly around the edge (shown as shaded areas in Figure 5.26 at t = 50 s). At t = 150 s, visibility in the foyer and western staircase has dropped below 5 m due to the open egress doors.

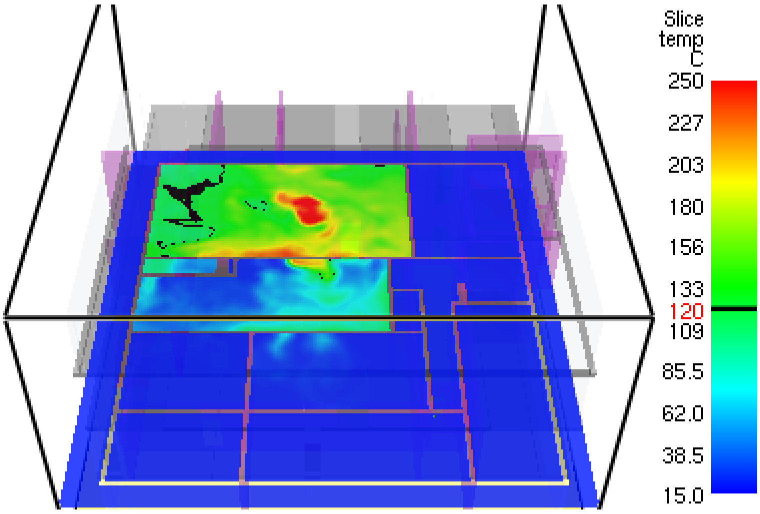


(Visibility at t = 50s)



(Visibility at t = 150s)

Figure 5.26: Visibility slice at 2 m in FDS for basement bar fire



(Temperature at t = 150s)

Figure 5.27: Temperature slice at 2 m in FDS for basement bar fire

The results of FDS versus BRANZFIRE are summarised in Table 5.30. The sprinkler activates at 142 s in FDS compared to 126 s in BRANZFIRE. There is good agreement between FDS and BRANZFIRE results.

Table 5.30: BRANZFIRE vs. FDS for fire at basement bar in the nightclub

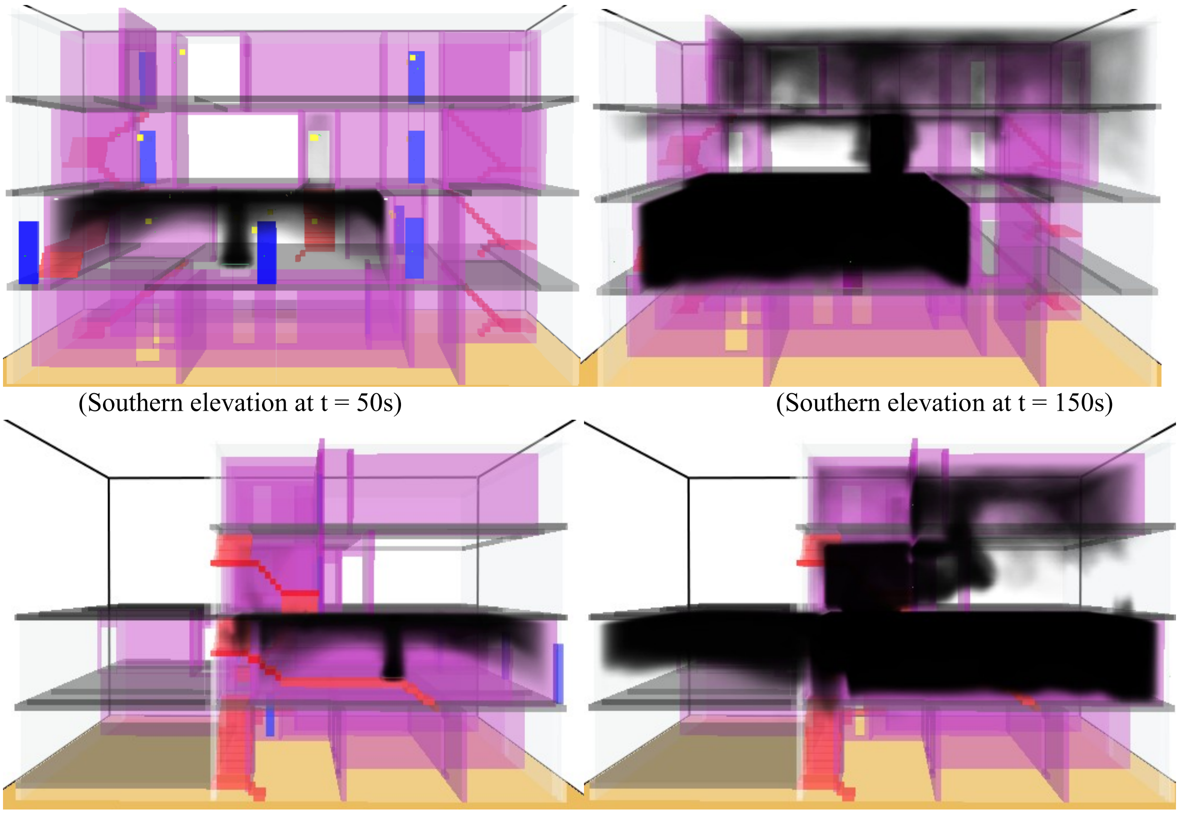
	Criteria	Time Reached (s)		Difference (%)*
		BRANZFIRE	**FDS**	
Detection Time (s)	-	126 (SPK)	142 (SPK)	12.7
Room of fire origin (Basement bar)	Visibility = 5 m	55	61	10.9
	FED Thermal = 0.3	155	158	2
	FED CO = 0.3	382	401	5
Firecell of fire origin (Basement foyer)	Visibility = 5 m	101	112	11
	FED Thermal = 0.3	328	274	- 16.4
	FED CO = 0.3	436	425	- 2.5

* *A negative value shows criteria is reached earlier in FDS than that in BRANZFIRE*

5.8.2 Ground Level Dance Fire

In this case, fire is located at the ground floor dance area and capped by sprinkler activation. The building is designed by performance-based fire engineering approach that the open stairway on the ground floor remains open. The locations of devices in FDS as well as plots at each location are attached in APPENDIX L-2.

Figure 5.28 shows the smoke development at t=50 s & 150 s. As the open stairway on the ground floor remains unenclosed, smoke quickly fills into the open stairway and spreads onto floors above. Smoke layer on Floor 3 descends much quicker than that on Floor 2.



(Southern elevation at t = 50s) (Southern elevation at t = 150s)

(Western elevation at t = 50s) (Western elevation at t = 150s)

Figure 5.28: Smoke development in FDS for fire at ground floor dance

The results of FDS versus BRANZFIRE are summarised in Table 5.31. The sprinkler activates at 137 s in FDS compared to 158 s in BRANZFIRE. Due to the limitations of BRANZFIRE in terms of allowable number of rooms and effective venting between floors, Floor 2 & 3 were not included in BRANZFIRE modelling but considered in FDS. There is good consistence between FDS and BRANZFIRE results for visibility and thermal effect with deviation less than 10% whilst the difference for FED CO is 21.5%.

Table 5.31: BRANZFIRE vs. FDS for ground floor dance fire

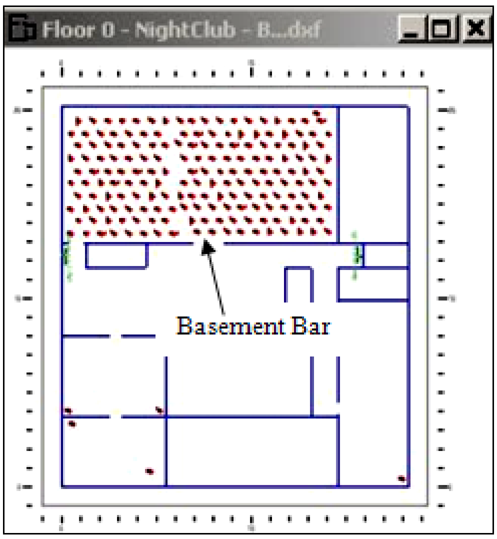
	Criteria	Time Reached (s)		Difference (%)*
		BRANZFIRE	FDS	
Detection Time (s)	-	158 (SPK)	137 (SPK)	-13.3
Room of fire origin (Dance floor)	Visibility = 5 m	78	79	1.3
	FED Thermal = 0.3	195	213	9
	FED CO = 0.3	470	571	21.5
Floor 2	Visibility = 5 m	N/A	174	-
	FED Thermal = 0.3		>900	-
	FED CO = 0.3		>900	-
Floor 3	Visibility = 5 m	N/A	143	-
	FED Thermal = 0.3		>900	-
	FED CO = 0.3		>900	-

* *A negative value shows criteria is reached earlier in FDS than that in BRANZFIRE*

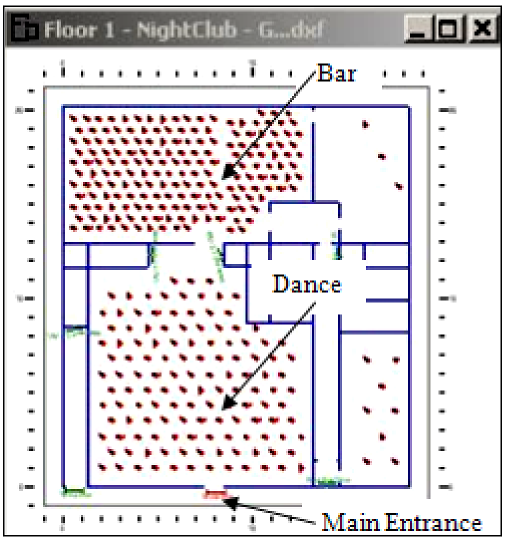
5.9 RSET Using Simulex

The egress calculation of the nightclub is more complicated than the other case study buildings as the nightclub has the most crowded occupancy that congestion / queuing occurs in most exitways. Besides, egress routes such as stairways, corridors, doorways are not equally sized. Hence, Simulex is used to further evaluate and compare results with the hand calculation. It is assumed fire is located in the Bar on the ground floor so that occupants in the bar (room of fire origin) start evacuation earlier than those away from the fire. Widths of egress are not increased and the two open stairways at basement and ground floor remain unenclosed, and occupants are allowed to egress through them.

The geometry of building layout and occupant distribution at the start of simulation are shown in Figure 5.29. Majority of the building occupants are crowded at bar or dancing area on Floor 1 – 2.



(Floor 0 – Basement)

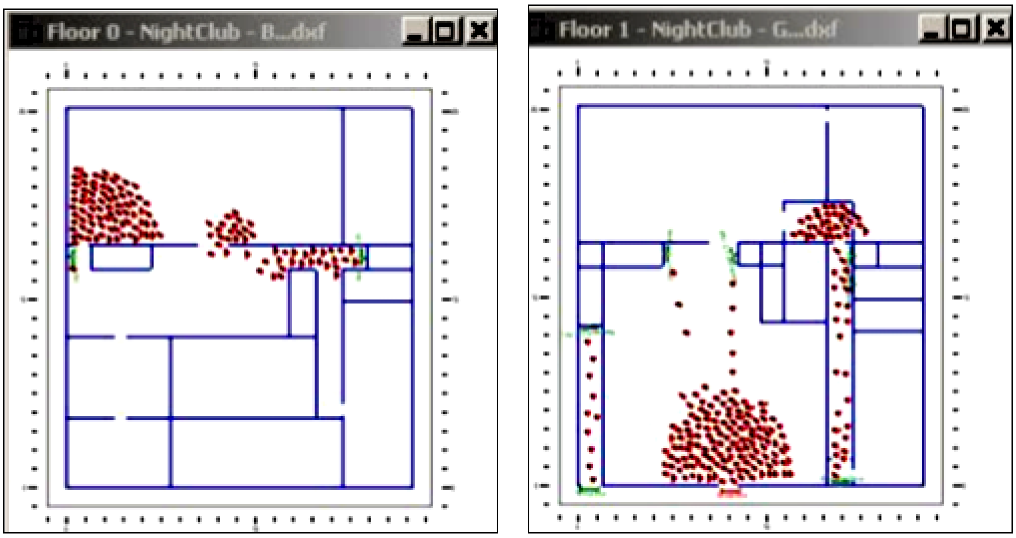


(Floor 1 – Ground floor)

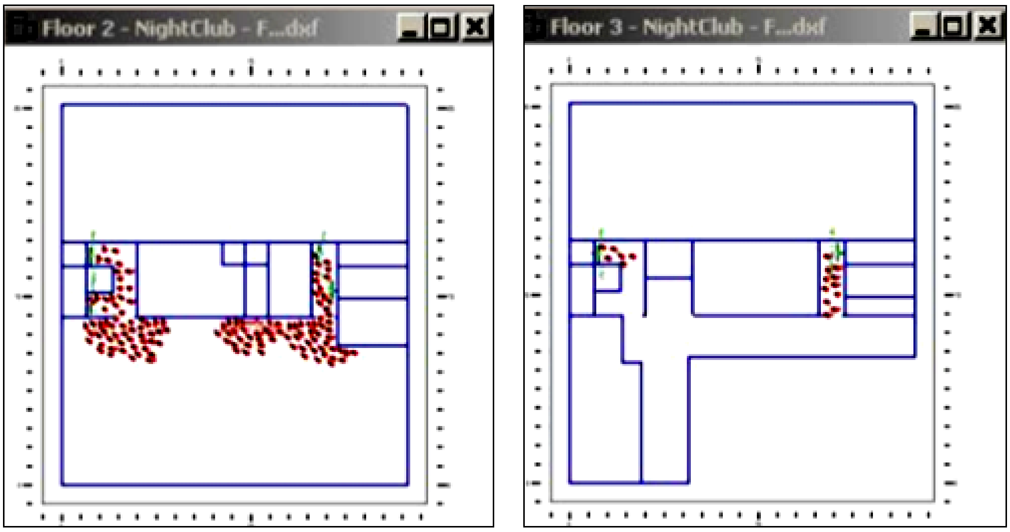
(Floor 2) (Floor 3)

Figure 5.29: Simulex input for the nightclub at t=0

Figure 5.30 shows the simulation results at t = 158 s after detection when all occupants on Floor 3 have cleared from this level. Meanwhile, occupants on Floor 0 – 2 are still queuing at the doorways.



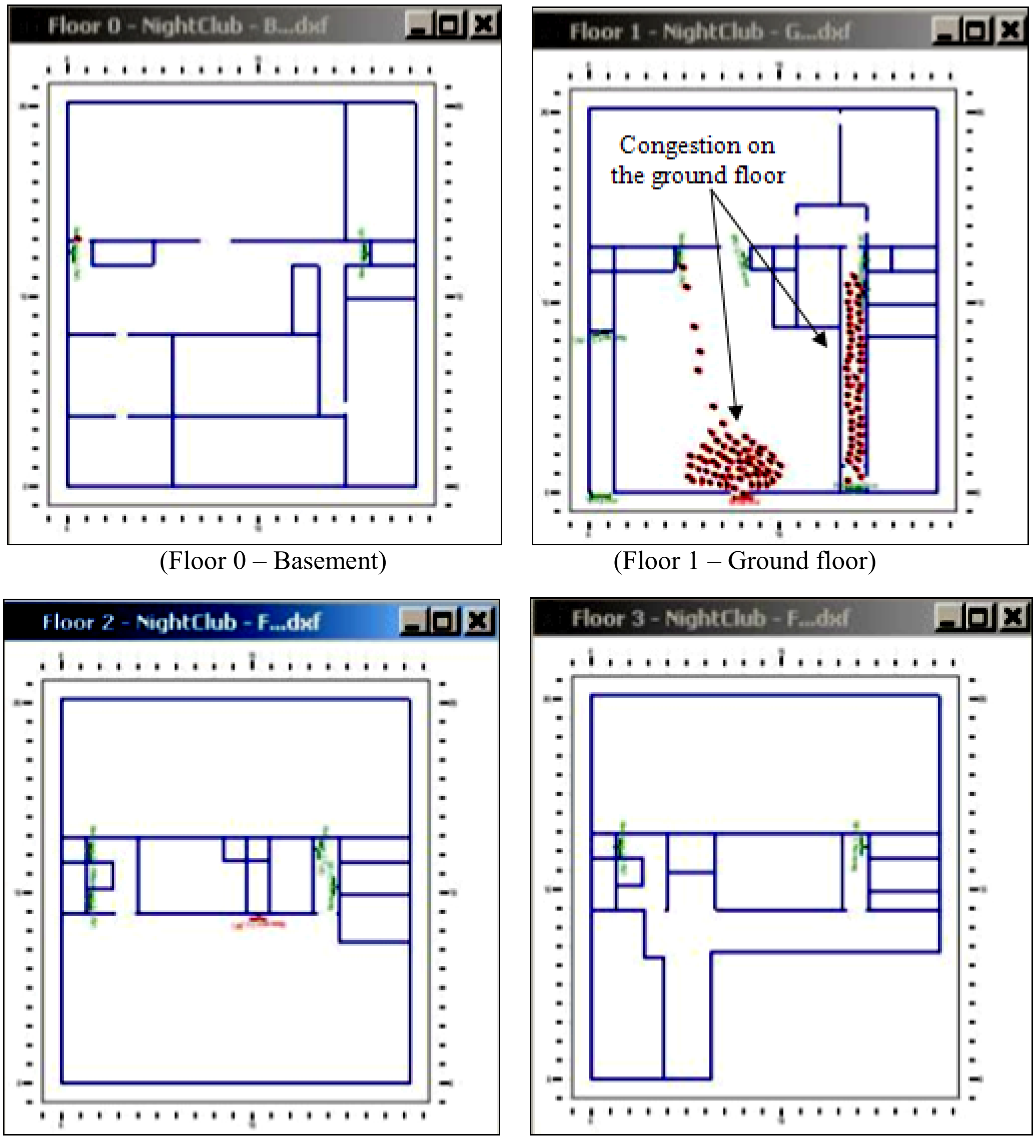
(Floor 0 – Basement) (Floor 1 – Ground floor)



(Floor 2) (Floor 3)

Figure 5.30: Simulex result for the nightclub at t=158s

Figure 5.31 shows the simulation results at t = 278 s after detector activation when the basement, Floor 2 and Floor 3 have been cleared. Occupants only present on the ground floor. They are either queuing at the main entrance or in the eastern corridor. Obviously, the bottleneck controlling the RSET of the entire building is the main entrance and the east corridor on the ground floor.



(Floor 0 – Basement) (Floor 1 – Ground floor)

(Floor 2) (Floor 3)

Figure 5.31: Simulex result for the nightclub at t=278s

The RSET results using Simulex compared to the hand calculation are summarised in Table 5.32. The detection time and pre-movement time are same as previous analysis. Simulex provides good agreement with hand calculation using the hydraulic model. A negative value means Simulex results in longer RSET than the hydraulic model. In most locations where queuing occurs, Simulex may provide slightly more conservative results than the hydraulic model.

Table 5.32: Simulex versus hand calculation for fire in the bar on the ground floor of nightclub

Events	RSET (s)		
	Hydraulic Model	**Simulex**	**Difference %**
Clear fire origin (Ground Bar)	247	248	-0.4%
Clear Floor 3	286	285	0.4%
Clear Floor 2	329	338	-3%
Clear Basement	357	405	-13.4%
Clear Main Entrance (Dance floor)	439	445	-1.3%
Clear Entire Building (Ground Corridor)	468	496	-6%

* *A negative value shows Simulex gives longer RSET than the hydraulic model*

CHAPTER 6 CASE STUDY 2 – HOSPITAL

6.1 Introduction

A hospital is a complex facility providing treatment or care of people suffering from physical or mental illness. They are made up of a number of different functional areas, including emergency, surgery, intensive care unit (ICU) and laboratory etc. which are dedicated to patient care and treatment. Meanwhile, there are also some supporting functions, such as retail shops and cafeterias etc.

The most crucial aspect of a building's fire safety is the possibility of safe escape in the event of fire. Evacuation process of a hospital can be complicate. Each space is expected to have much different occupant characteristics and patient-to-staff ratios which result in different evacuation requirements. Because some patients are incapable of movement, spaces such as surgical theatres are required to remain functional in the event of fire and occupants must be defended in place. Patients in intensive care unit (ICU) are often connected to various life support devices, making movement very difficult and time-consuming.

Even though studies show relatively low fuel loads within most spaces in healthcare facilities, higher fuel loads may be anticipated in some spaces such as medical libraries, X-ray file rooms, linen storage and general storage rooms[62]. In 1990, a fire started in a linen storage room of Dardanelle Nursing Home in Arkansas, US, which resulted in the death of four of the eighty five patients due to smoke inhalation. Factors contributing to the loss of life include: the absence of a complete sprinkler system; the failure of the compartmentation of fire origin to contain the fire; and the spread of fire and smoke through concealed space[63].

Hospital fires often involve combustible beddings. In 1994, a fire occurred in a 468-bed 7-storey hospital in Petersburg, Virginia, and resulted in the deaths of four patients[64]. The fire began in patient's room likely as the result of patient smoking and ignited bedding which was believed to contain 7-9 kg of foam plastic materials in each mattress. Factors contributing to the loss of life include: no sprinkler protection in area involved in the incident (the building was partially sprinklered); fire intensified by 100% oxygen released from the hospital's oxygen distribution system; Door to room of origin was left open allowing smoke and heat spreading into the corridor; No smoke detectors were provided in patient rooms for early warning; and heavy fire load in patient rooms including highly combustible foam plastic beddings.

Hence, fire safety design for a complex hospital building can be challenging in terms of the physical / mental condition and alertness of patients for evacuation, staff response and availability for assistance in emergency, the nature of a hospital to remain functional in disaster, higher requirements for compartmentation (e.g. in areas for patient care) to prevent fire / smoke spread etc. This chapter presents a case study for a four-storey hospital complex building to evaluate the appropriateness and completeness of the proposed C/VM2.

6.2 Building Description

The premise is a four-storey hospital complex building with the primary access through the south main entrance on the ground floor (Floor 1) as shown in Figure 6.1. The core functions on the ground floor include Diagnostic imaging, Cafeteria, Physiotherapy, Emergency and Admitting. Each department can be accessed by interconnected corridors. The cafeteria is open for both hospital staff and visitors. No overnight sleeping patients present on the ground floor. Access to upper floors is provided by five staircases shown by the dotted green arrows. Egress out of the building can be either via the south main entrance, or emergency entrance or the northwest exit shown by the solid red arrows.

The core functions on the second floor (Floor 2) include Laboratory, Storage, Surgery Suite and Chronic care. The Chronic Care Unit provides sleeping accommodation of 17 beds for inpatients to sleep overnight. As shown in Figure 6.2, the second floor can be accessed by five internal staircases shown by the solid red arrows, while two of them have direct exit to outside on the ground floor.

The core functions on the third floor (Floor 3) include Intensive Care Unit (ICU), Surgical Unit, Cancer Care Unit and Hostel. The ICU provides care to critically ill patients and have total of 4 beds. The Surgical Unit is where patients are hospitalized to receive medicines and treatments both prior to and / or following surgery. It contains total of 15 beds for inpatient services. Hostel provides accommodation for patients' families and has total of 50 beds. The Cancer Care Unit provides cancer diagnostic service for up to 10 beds for inpatients sleeping overnight. Egress from this level can be via five internal staircases shown by the solid red arrows in Figure 6.3.

The core functions on the fourth floor (Floor 4) include Psychiatric Unit and Maternity. The Maternity is where patients are under care for delivery and recovery. It has 7 inpatient guest rooms with total of 8 beds, two birthing rooms and two newborn care rooms for up to 8 newborn babies. The Psychiatric Unit provides treatment of mental disorders in short-term or outpatient therapy for low-risk patients. Egress from this level can be via five internal staircases shown by the solid red arrows in Figure 6.4.

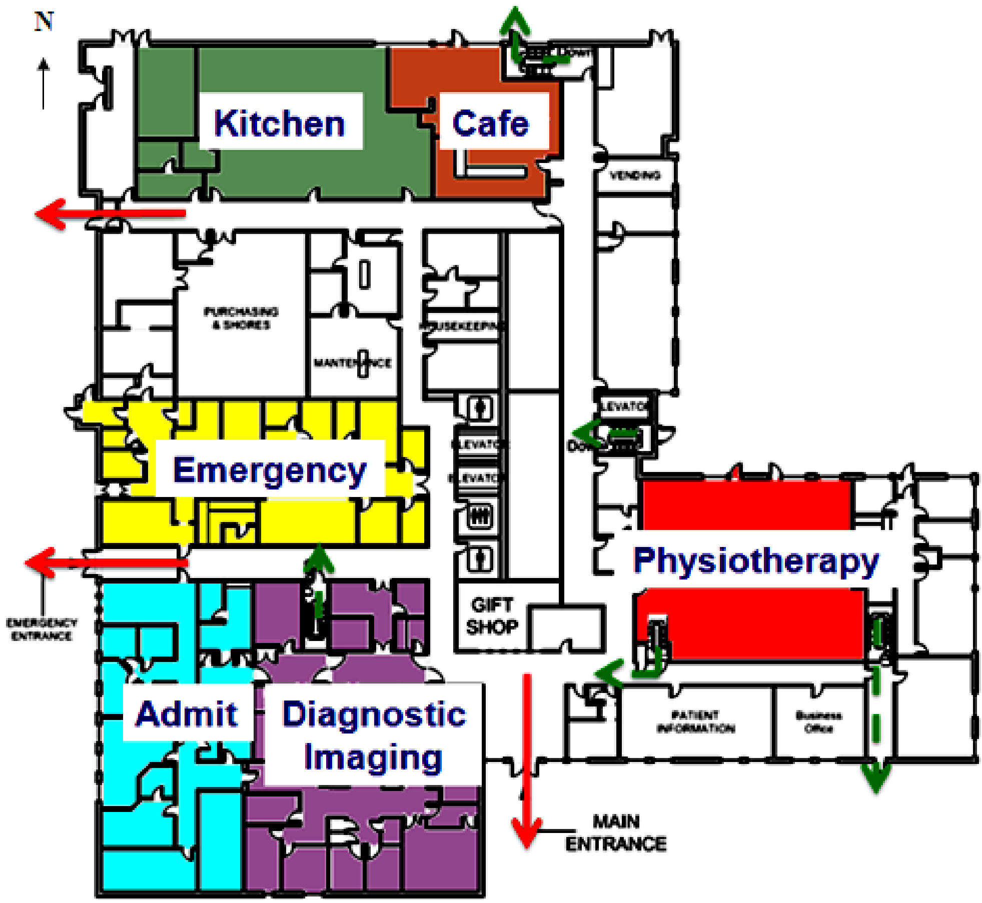


Figure 6.1: Hospital floor plan – Ground floor (Floor 1)

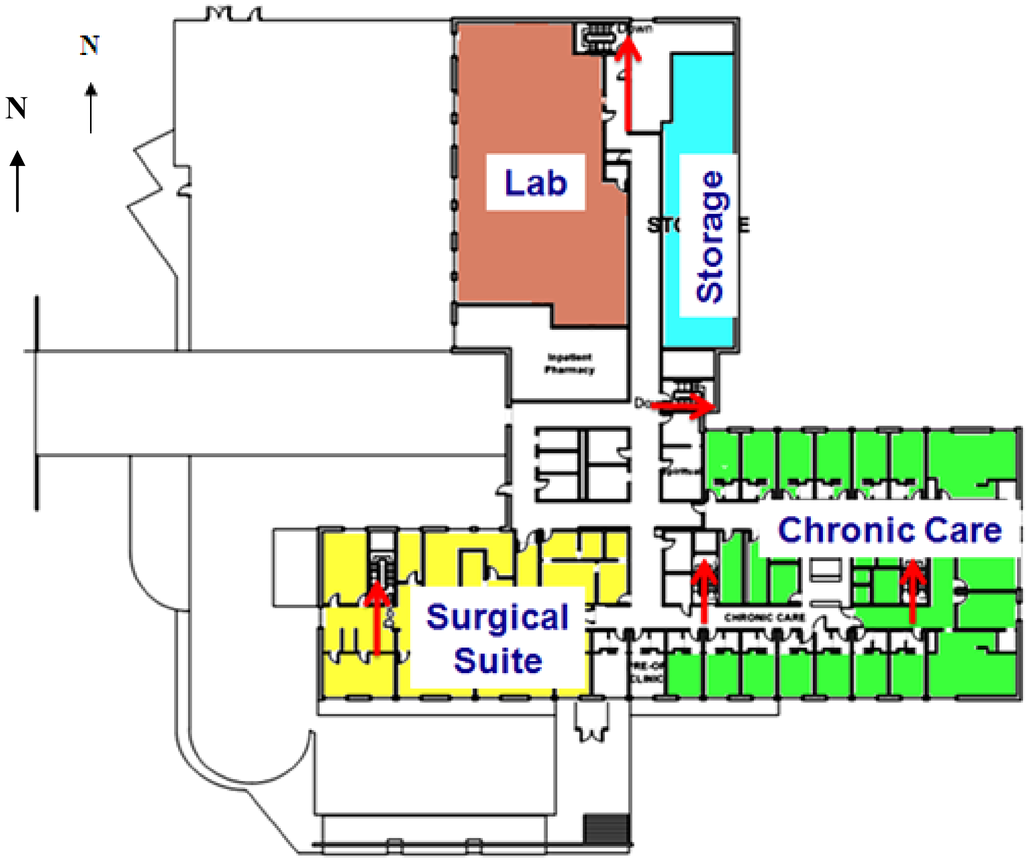


Figure 6.2: Hospital floor plan – Floor 2

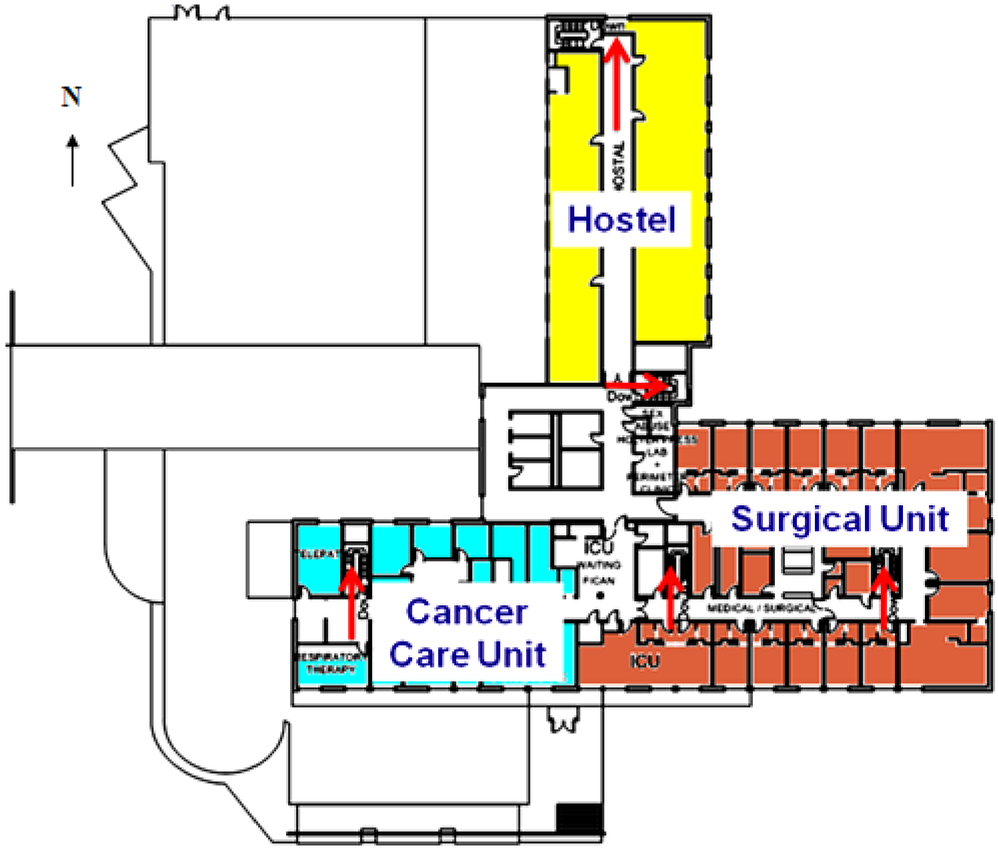


Figure 6.3: Hospital floor plan – Floor 3

Figure 6.4: Hospital floor plan – Floor 4

6.3 C/AS1 Design

6.3.1 Purpose Groups, Fire Hazard Category and Occupant Loads

The Purpose Group, Fire Hazard Category (FHC) and occupant loads for the hospital are summarised in Table 6.1. The building has total of 1139 occupants while over half of the occupants present on the ground floor. Occupant loads in Physiotherapy, Emergency and Surgical Suite are counted based on the number of staff available. Occupants in Hostel, Surgical Unit, ICU, Cancer Care Unit and Maternity are counted by number of beds provided. The other spaces are calculated based on the density specified in *C/AS1 Table 2.2* multiplied by the floor area.

Table 6.1: Purpose group, FHC and occupant loads - Hospital

	Location	PG	FHC	Occupant Density (persons/m^2)	Area (m^2)	Occupant load (persons)
Floor 1 (Ground floor)	Kitchen	WL	2	0.1	577	58
	Cafeteria	CL	2	0.8	280	224
	Storage	IA	1	0.02	360	7
	Maintenance & Service	IA	1	0.03	408	12
	Staff Rooms	WL	2	0.1	651	65
	Gift Shop	WL	2	0.1	92	9
	Patient Information	WL	2	0.1	195	20
	Business Office	WL	2	0.1	103	10
	Board Room & Office	WL	2	0.1	302	30
	Physiotherapy	WL	2	-	625	50
	Emergency	WL	2	-	845	30
	Admit	WL	2	0.1	648	65
	Diagnostic Imaging	WL	2	0.1	1070	107
	Total occupant loads (Floor 1)					**687**
Floor 2	Lab	WL	2	0.1	892	89
	Storage	IA	1	0.02	490	10
	Inpatient Pharmacy	WL	2	0.1	223	22
	Pre-Op Waiting Room	WL	2	0.5	23	12
	Pre-Op	WL	2	0.1	43	4
	Chronic Care Unit	SC	2	-	-	17
	Surgical Suite	WL	2	-	-	20
	Total occupant loads (Floor 2)					**174**
Floor 3	Hostel	SA	2	-	-	50
	Surgical Unit	SC	2	-	-	15
	ICU	SC	2	-	-	4
	Cancer Care Unit	SC	2	-	-	10
	Total occupant loads (Floor 3)					**79**
Floor 4	Psychiatric Unit	WL	2	0.1	896	90
	Maternity	SC	2	-	-	16
	Offices	WL	2	0.1	930	93
	Total occupant loads (Floor 4)					**199**
Total occupant loads of the building						**1139**

6.3.2 Requirements for Firecells

Under the C/AS1, the building is divided into the following firecells to control fire spread as shown in Figure 6.5 to Figure 6.8 for each level.

- Each floor shall be separate firecells;
- All staircases shall be enclosed as safe paths and provide egress directly to a safe place;
- Where hospital wards provide sleeping accommodation for patients who may or may not be known to one another, group sleeping areas shall be separate firecells with no greater than 12 beds for a single group sleeping area firecell. Hence, the Cancer Care Unit (Floor 3) with no more than 12 beds shall be a separate firecell. The Chronic Care, Surgical Unit and Maternity shall be separated into two firecells where total number of beds exceeds 12. Each firecell can be subdivided by non-fire rated partitions having a gap of no less than 400 mm between the top of the partitions and the underside of the ceiling;
- According to *Clause 5.6.9 C/AS1*, Surgical Suite shall be a separate firecell where evacuation is not desirable;
- According to *Clause 6.6.6 C/AS1*, within the Surgical Suite, Intensive Care Units (ICU), and Maternity firecells, each space shall be separated smokecells from adjacent spaces;
- All lifts and service shafts shall be enclosed within protected shafts.

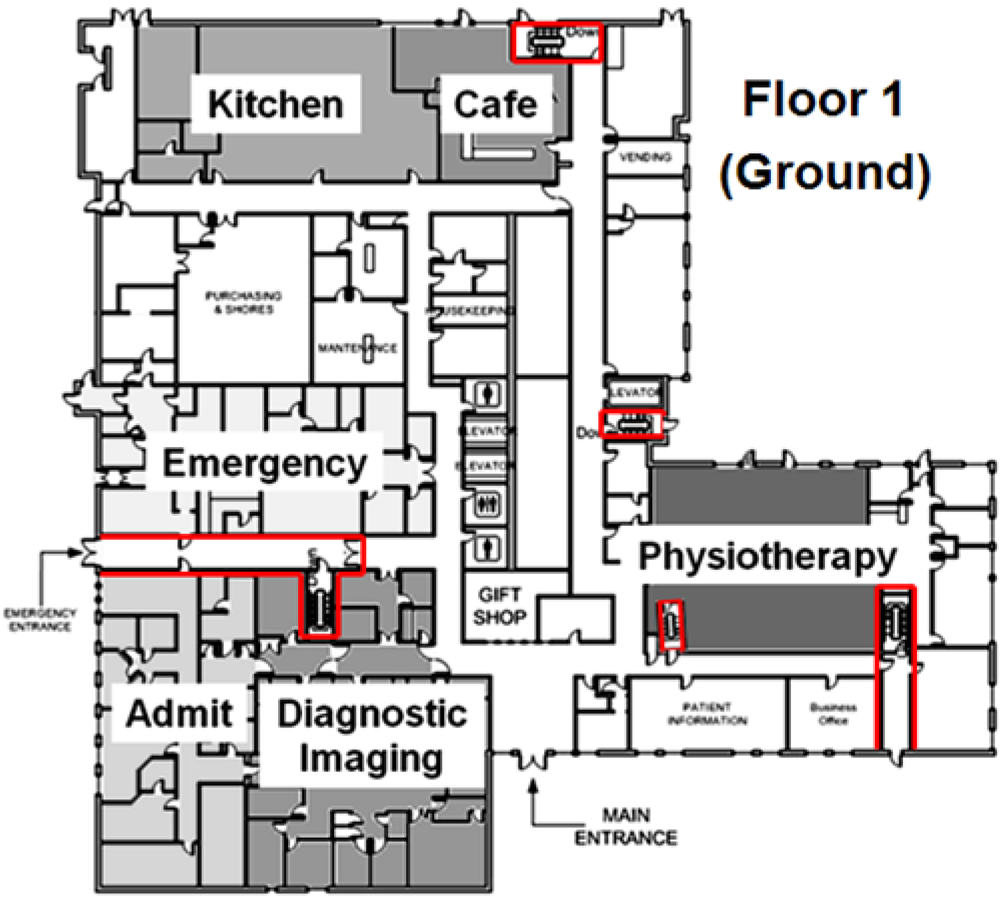


Figure 6.5: Firecell separation of the proposed hospital on Floor 1

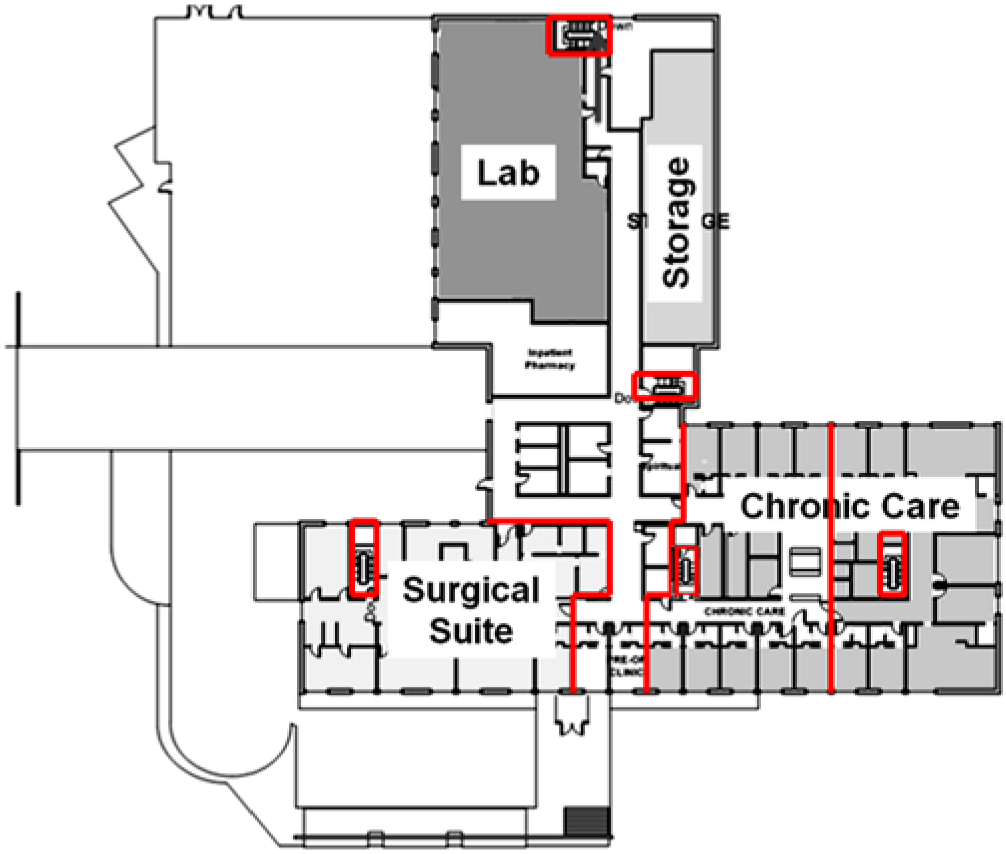


Figure 6.6: Firecell separation of the proposed hospital on Floor 2

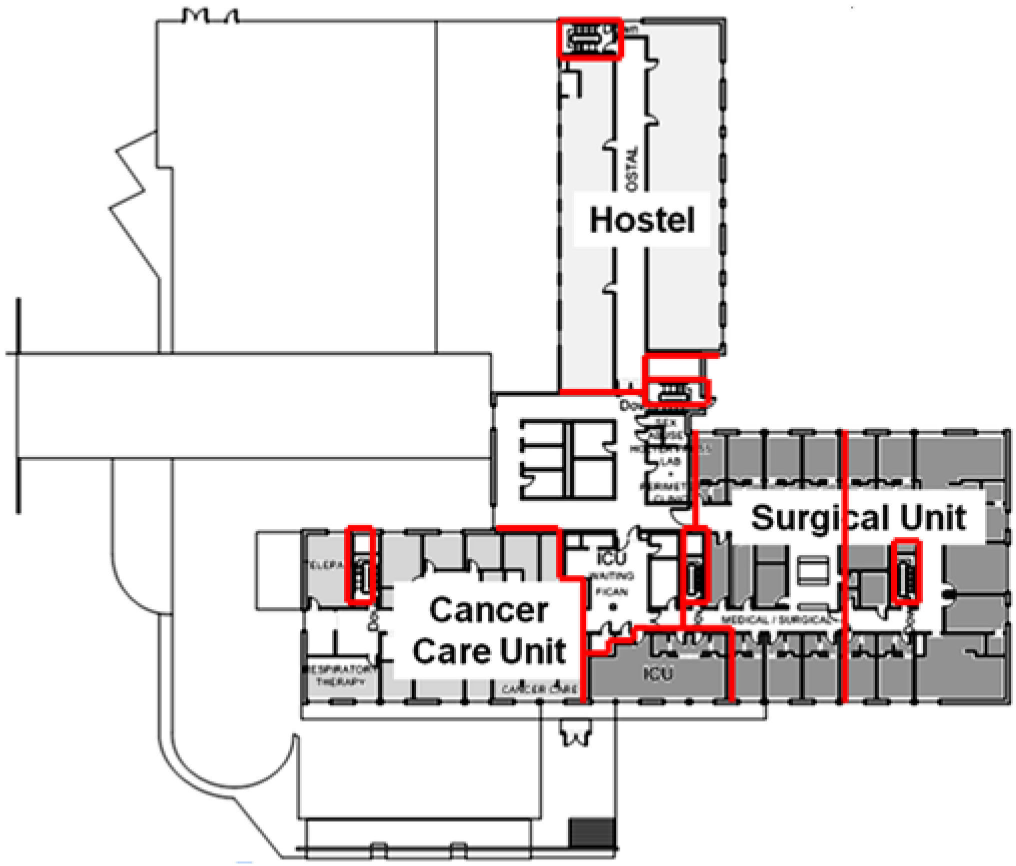


Figure 6.7: Firecell separation of the proposed hospital on Floor 3

Figure 6.8: Firecell separation of the proposed hospital on Floor 4

For this building height and occupancy, the minimum firecell ratings, alarm types and fire safety systems are summarised in Table 6.2. Where a floor contains occupants sleeping and under care (purpose group SC), all lower floors shall, regardless of the purpose group contained, have sprinkler system. All safe path staircases shall be fire separated from adjacent firecells having FRR no less than 30/30/30. The higher of F or S ratings shall be applied to SC sleeping occupants and surgical suites, which will be further addressed in Section 6.3.4. As the building will be fully sprinklered, the hostel SA firecell is permitted to contain up to 160 beds; ventilation is not required in exitways for purpose group SC; and firecell floor area can be unlimited.

Table 6.2: Fire safety precautions in the hospital

Firecell Location	Escape Height (m)	PG	F Rating (minutes)	Alarm Type	Other Protection Required
Floor 1 (Ground)	0	CL	0	SPK, MCPs	▪ Visibility in escape routes ▪ Fire Hydrant system
Floor 2	2.5	SC	30	SPK, SD, MCPs	▪ Visibility in escape routes ▪ Fire Hydrant system
		WL	30	SPK, MCPs	▪ Visibility in escape routes ▪ Fire Hydrant system
Floor 3	5	SC	30	SPK, SD, MCPs	▪ Visibility in escape routes ▪ Fire Hydrant system
		SA	30	SPK, MCPs	▪ Visibility in escape routes ▪ Fire hose reels ▪ Fire Hydrant system
Floor 4	7.5	SC	30	SPK, SD, MCPs	▪ Visibility in escape routes ▪ Fire Hydrant system
		WL	30	SPK, MCPs	▪ Visibility in escape routes ▪ Fire Hydrant system

Key: SPK – Sprinkler SD – Smoke detectors MCPs – Manual Call Points

6.3.3 Means of Escape

6.3.3.1 Number and Width of Escape Routes

As the building will be sprinklered, it is not required to provide extra width to allow for the possibility that one escape route may be unusable. The required number and width of escape routes are summarised in Table 6.3. It shall be noticed that the individual door width for SC occupants shall achieve minimum of 1200 mm for horizontal travel and 1500 mm for vertical travel.

Table 6.3: Width and Number of Escape Routes – Hospital

Location		Serving Occupancy (persons)	Number of Egress		Type of Travel	Width (mm)	
			Required	Available		Required	Available
Floor 1	Kitchen	58	2	3	H	850	2580
	Cafeteria	224	2	2	H	1568	1720
	Storage	7	1	2	H	850	1720
	Maintenance	6	1	2	H	850	1720
	Staff room	14	1	1	H	850	860
	Gift shop	9	1	1	H	850	860
	Patient Information	20	1	1	H	850	860
	Business office	10	1	1	H	850	860
	Board room	9	1	1	H	850	860
	Physiotherapy	50	1	2	H	850	1720
	Emergency	30	1	3	H	850	4300

Location		Serving Occupancy (persons)	Number of Egress		Type of Travel	Width (mm)	
			Required	Available		Required	Available
	Admit	65	2	3	H	850	3440
	Diagnostic	107	2	3	H	850	4300
Floor 2	Lab	89	2	3	H	850	2580
	Storage	10	1	2	H	850	1720
	Inpatient Pharmacy	22	1	2	H	850	1720
	Pre-op Waiting	12	1	1	H	850	860
	Pre-op	4	1	1	H	850	860
	Chronic care	17	2	2	H	1200	1720
	Surgical suite	20	1	2	H	850	2580
	Non-sleeping Stair	53	-	-	V	1000	1600
	Stair in SC firecell	9	-	-	V	1500	1600
Floor 3	Hostel	50	1	2	H	850	1720
	Surgical unit	19	2	2	H	1200	1720
	ICU	4	1	1	H	1200	3600
	Cancer care	10	2	2	H	1200	1720
	Stair in SA firecell	50	-	-	V	1000	1600
	Stair in SC firecell	11	-	-	V	1500	1600
Floor 4	Psychiatric unit	90	2	2	H	850	1720
	Maternity	16	2	2	H	1200	1720
	Office Unit	93	2	2	H	850	1720
	Stair for SC	8	-	-	V	1500	1600

6.3.3.2 Length of Escape Routes

The allowed maximum and actual travel distances for the given purpose groups are summarised below in Table 6.4. There is 100 % allowable increase for WL, CL, IA purpose groups and 50 % allowable increase for SA purpose group as the building is sprinklered. However, no allowable increase is permitted for SC purpose group regardless of the sprinkler system. It shall be noticed that for SC purpose groups, the required combined width shall be 8mm/person for horizontal travel (7 mm/person for other PG) and 10 mm/person for vertical travel (9 mm/person for other PG). Length of escape routes in the hospital comply with that allowed in C/AS1.

Table 6.4: Length of Escape Routes - Hospital

Location		PG	Dead End Open Path (m)		Total Open Path (m)	
			Allowed	Actual	Allowed	Actual
Floor 1	Kitchen	WL	48	6	120	92
	Food Service	WL	48	12	120	29
	Cafeteria	CL	36	6	90	47
	Storage	IA	72	6	180	48
	Maintenance	IA	72	20	180	70
	Staff Room	WL	48	27	120	71
	Gift Shop	WL	48	22	120	52
	Patient Information	WL	48	28	120	56
	Business Office	WL	48	20	120	68
	Board Room	WL	48	20	120	42
	Physiotherapy	WL	48	6	120	52
	Emergency	WL	48	13	120	47
	Admit	WL	48	21	120	81
	Imaging	WL	48	16	120	72
Floor 2	Lab	WL	48	35	120	81
	Storage	IA	72	18	180	35
	Inpatient Pharmacy	WL	48	15	120	37
	Pre-op Waiting	WL	48	9	120	53
	Pre-op	WL	48	13	120	41
	Surgical Suite	WL	48	15	120	31
	Chronic Care Unit	SC	18	15	45	33
Floor 3	Hostel	SA	27	21	67	43
	ICU	SC	18	16	45	19
	Cancer Care Unit	SC	18	16	45	43
	Surgical Unit	SC	18	15	45	33
Floor 4	Psychiatric Unit	WL	48	14	120	36
	Maternity	SC	18	15	45	33
	Offices	WL	48	15	120	57

6.3.4 Internal and External Spread of Fire and Smoke

6.3.4.1 Fire Resistant Rating

As the building is under one ownership and not beside any boundaries, the required fire rating throughout the building is the F-rating except that S-rating (shown in Table 6.5) shall be applied for purpose group SC firecells and any firecells remaining occupied during fire. According to *Clause 6.6.7 C/AS1*, intermittently occupied spaces used for direct support functions to SC sleeping areas (e.g. treatment rooms, tea bays and sanitary facilities) may be included in those firecells if FHC is no greater than 1. Spaces providing communal service functions to adjacent SC sleeping areas (e.g. nurses stations, lounges and dining rooms etc) shall be sprinklered and fire separated having FRR no less than 30/30/30.

Table 6.5: S Rating for SC firecells

Variable	Value
A_v/A_f	0.1
A_h/A_f	0
FHC	2
t_e *(from Table 5.1 C/AS1)*	120
k	0.5
S Rating = $k \cdot t_e$	60 minutes

6.3.4.2 Surface Finishes

The exterior and interior surface finishes for this occupancy must meet the requirements of C/AS1 with respect to inhibiting the spread of fire. The interior surface finishes of the walls, ceilings, floor linings, and air ducts serving more than one firecell in purpose groups SC, SA, IE, CL, shall have surface finishes satisfying the following requirements as shown below in Table 6.6.

Table 6.6: Requirements for Surface Finishes in the hospital

Building Elements	Purpose Group or Location	SFI	SDI	FI
Walls, Ceilings (Coverings)	Exit way	0	3	-
	Sleeping areas in SC			
	All occupied spaces in purpose groups CL	2	5	-
	Sleeping area in SA			
	Passageways, corridors and stairways not being part of an exitway	7	5	-
Flooring (Coverings)	Exitways	Non-combustible or have low radius of effects of ignition		
	Any occupied space in SC purpose group			
Ducts for HVAC systems	Internal surfaces	0	3	-
	External surfaces	7	5	-
Acoustic treatment and pipe insulation	Within air-handling plenum in SC and SA	7	5	
Suspended flexible fabrics	All occupied spaces in CL including exitways	-	-	12
	Exitways serving SC and SA			
	Underlay to exterior cladding or roofing when exposed to view in occupied spaces in purpose groups SC,SA, WL, CL and IE	-	-	5
Membrane structures	Purpose groups CL	-	-	12

Key: SFI = spread of flame index SDI = smoke developed index FI = flammability index

In firecells constructed without foamed plastics, and equipped with sprinklers, only the ceiling shall comply with the SFI and SDI requirements. Where foamed plastic building materials are used in wall, ceiling or roof systems, the foamed plastics materials shall meet the following requirements as shown in Table 6.7.

Table 6.7: Requirements for foamed plastics materials in hospital

Application	Required Properties		
	SA	SC	CL, WL, IA
Sleeping areas	fb + p	fb + p	-
Exitways sprinklered	fb + p	fb + p	fb + p
Non-sleeping occupied spaces sprinklered	sf + p	fb + p	sf + p
Concealed spaces	p	fb + p	p

Key: *p – foamed plastics shall comply with the flame propagation criteria as specified in AS 1366*
fb – flame barrier complying with Appendix C C9.1 of C/AS1

6.3.5 Fire Fighting

The building is considered having Fire Service vehicular access within 18 m on the south and west side of the building. Fire hydrant system will be installed throughout the building as Fire Service hose run distance, from the Fire Service vehicular access to any point on any floor exceeds 75 m. Fire hydrant systems shall comply with *NZS 4510:2008 Fire Hydrant Systems for Buildings*[61]. According to *Clause 8.2.4 C/AS1*, in a building not required to have a fire systems centre, the control features shall contain all control panels indicating the status of fire safety systems installed in the building, together with all control switches. Hand operated firefighting equipments, e.g. fire extinguishers, shall be provided and installed in compliance with *NZS 4503:2005 Hand Operated Fire-fighting Equipment*[59].

6.3.6 Summary of Design Features to Comply with C/AS1

The following design features are required to comply with C/AS1:

- The building shall be fully sprinklered with manual call points. Smoke detectors are required in all firecells containing occupants sleeping and under care. All detectors shall be interconnected;
- All SC sleeping firecells, the Surgical Suites firecell and adjoining safe path staircases shall have FRR of 60/60/60. All other firecells shall have FRR no less than 30/30/30;
- Width of escape for SC purpose group shall be increased to achieve 1200 mm for horizontal travel and 1500 mm for vertical travel;
- All locking devices on doors on escape routes should be clearly visible, located where such a device would be normally expected, designed to be easily operated without a key or other security device, and allow the door to open in the normal manner;

- Doors on escape routes are required to open in the direction of escape if there are more than 20 occupants (or 10 occupants into exitways) using the doors;
- Doors within fire separation shall achieve a FRR same as required for the fire separation;
- Fire hydrant riser is required as Fire Service vehicular access to any point on any floor exceeds 75 m. Fire hose reels are to be provided on Floor 3;
- Illuminated exit signage is required throughout the building in accordance with F8/AS1;
- Emergency lighting is required throughout the building in accordance with F6/AS1;
- Interior surfaces shall meet the requirements as in Table 6.6 and Table 6.7.

6.4 C/VM2 Analysis

6.4.1 DFS 1 – Challenging Fire

Any room / space having area greater than 200 m^2 or with occupant load greater than 150 require analysis under Fire Scenario 1, including Kitchen, Cafeteria and Physiotherapy on Floor 1; Lab and Storage on Floor 2; and Hostel on Floor 3. All other rooms are less than 200 m^2 and have less than 150 occupants. Kitchen and storage are not analysed which have fewer occupants than Cafeteria and Lab. The other four locations will be analysed using BRANZFIRE modelling to determine the available safe egress time.

6.4.1.1 ASET – BRANZFIRE Modelling

The building construction materials for interior walls, ceilings and floors in BRANZFIRE modelling are summarised in Table 6.8. The design fire parameters are specified as the proposed C/VM2. An example input file in BRANZFIRE for fire in the Cafeteria on the ground floor is attached in APPENDIX H-2.

Table 6.8: Construction materials as modelled in BRANZFIRE – Hospital

	Wall	Ceiling	Floor
Surface	16mm plasterboard	100mm concrete	100mm concrete
Substrate	100mm concrete	-	-

(1) Cafeteria & Physiotherapy Fire at Ground Level

Figure 6.9 shows the geometry input in BRANZFIRE for fire in Cafeteria or Physiotherapy on the ground floor. Due to the limited number of rooms allowable in BRANZFIRE, only those rooms of interest are considered in the modelling including the Cafeteria, Physiotherapy, interconnected corridors and stairs.

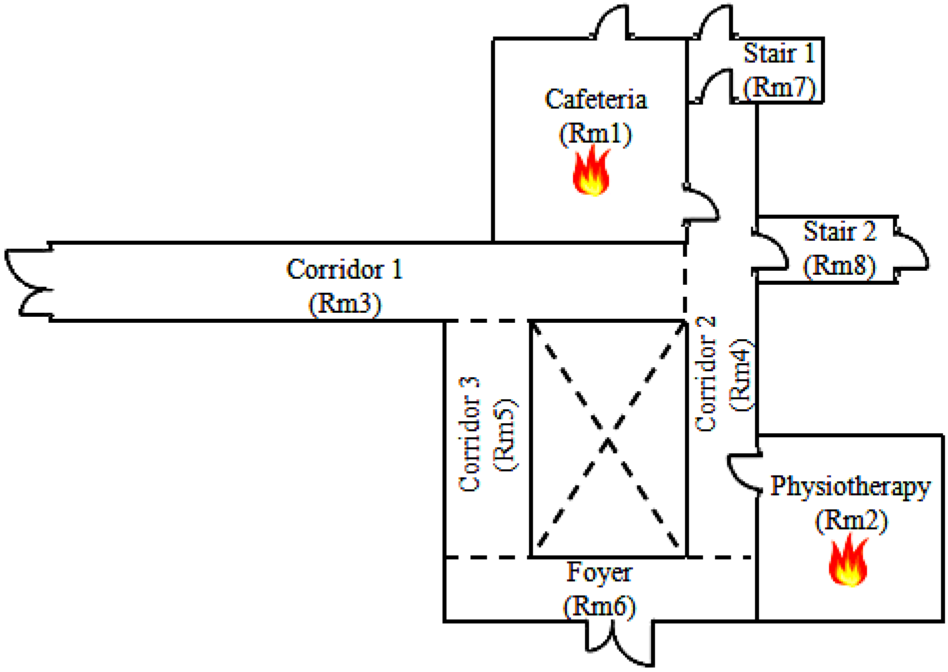


Figure 6.9: Geometry as modeled in BRANZFIRE – Cafeteria & Physiotherapy fire at ground level

The geometry of rooms and details of vents used in BRANZFIRE modelling are given in Table 6.9 and Table 6.10. Egress doors with self-closers are taken as half-width for ventilation flow over the time period they are open as specified in the proposed C/VM2.

Table 6.9: Geometry of rooms as modeled in BRANZFIRE – Fire on Floor 1

Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height (m)
Cafeteria	1	20	14	2.5	0	2
Physiotherapy	2	26.5	23.6	2.5	0	2
Corridor 1	3	54	3.6	2.5	0	2
Corridor 2	4	74	3.4	2.5	0	2
Corridor 3	5	54	4.2	2.5	0	2
Foyer	6	26	9.2	2.5	0	2
Stair 1	7	7	3.4	10	0	9.5
Stair 2	8	7	3.4	10	0	9.5

Table 6.10: Geometry of vents as modeled in BRANZFIRE – Fire on Floor 1

Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)
1 to 3	0.02	2.5	0	Leakage	Open	Always
1 to 4	0.86	2	0	Door	Open	Always
1 to outside	0.43	2	0	External door	Self-closing	154
	0.01	2.5	0	Leakage	Open	Always
2 to 4	0.86	2	0	Door	Open	Always
2 to 6	0.024	2.5	0	Leakage	Open	Always
2 to outside	0.025	2.5	0	Leakage	Open	Always
3 to 4	3.6	2.5	0	Open wall	Open	Always
3 to 5	4.2	2.5	0	Open wall	Open	Always
3 to outside	0.86	2	0	External door	Self-closing	173
4 to 6	3.4	2.5	0	Open wall	Open	Always
4 to 7	0.44	2	0	Fire door	Self-closing	75
4 to 8	0.44	2	0	Fire door	Self-closing	89
5 to 6	4.2	2.5	0	Open wall	Open	Always
6 to outside	0.86	2	0	External door	Self-closing	94
7 to outside	0.43	2	0	External door	Self-closing	75
	0.007	10	0	Leakage	Open	Always
8 to outside	0.43	2	0	External door	Self-closing	89
	0.003	10	0	Leakage	Open	Always

(2) Lab Fire on Floor 2

Figure 6.10 shows the geometry of rooms in BRANZFIRE modelling for fire in the Lab on Floor 2 including the Lab, corridor as part of the egress route connecting the Chronic Care to the staircases.

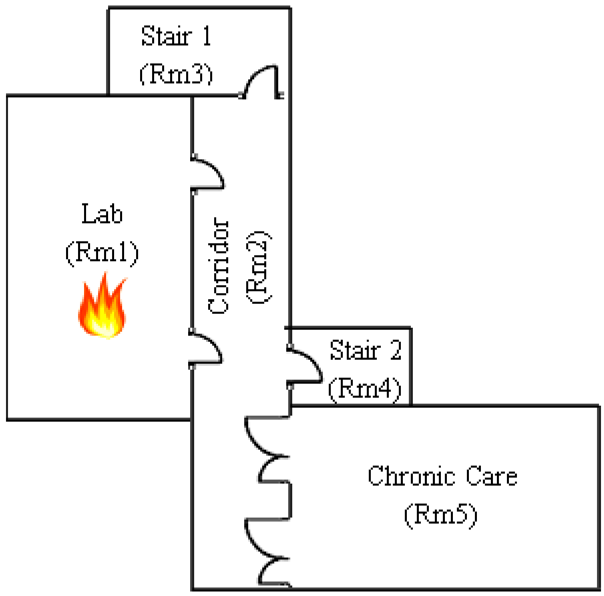


Figure 6.10: Geometry showing the rooms as modeled in BRANZFIRE – Lab fire on Floor 2

Table 6.11 and Table 6.12 give the details of room and vent geometries in BRANZFIRE modelling.

Table 6.11: Geometry of rooms as modeled in BRANZFIRE – Floor 2 Lab fire

Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height (m)
Lab	1	39	23	2.5	2.5	2
Corridor	2	76	5.4	2.5	2.5	2
Stair 1	3	7	3.4	10	0	9.5
Stair 2	4	7	3.4	10	0	9.5
Chronic Care	5	36	8.7	2.5	0	2

Table 6.12: Geometry of vents as modeled in BRANZFIRE – Floor 2 Lab fire

Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)
1 to 2	0.86	2	0	Door	Open	Always
	0.86	2	0	Door	Open	Always
1 to outside	0.055	2.5	0	Leakage	Open	Always
2 to 3	0.44	2	0	Fire door	Self-closing	88
2 to 4	0.44	2	0	Fire door	Self-closing	88
2 to 5	0.86	2	0	Fire door	Self-closing	18
	0.86	2	0	Fire door	Self-closing	18
2 to outside	0.017	2.5	0	Leakage	Open	Always
3 to outside	0.007	10	0	Leakage	Open	Always
4 to outside	0.003	10	0	Leakage	Open	Always

(3) Hostel Fire on Floor 3

Figure 6.11 shows the geometry of rooms in BRANZFIRE for fire in the Hostel on Floor 3 including the room of fire origin and corridor and foyer as part of the egress route connecting to the staircases. Table 6.13 and Table 6.14 give the details of rooms and vents in the modelling.

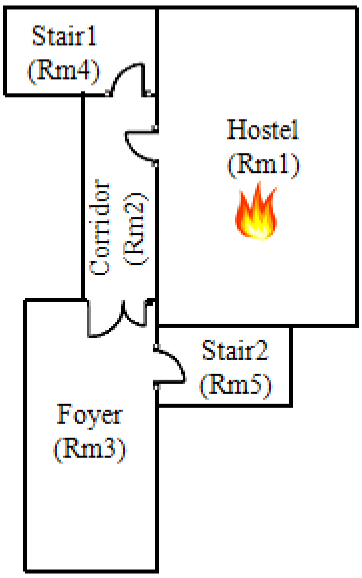


Figure 6.11: Geometry showing the rooms as modeled in BRANZFIRE – Hostel fire on Floor 3

Table 6.13: Geometry of rooms as modeled in BRANZFIRE – Hostel fire on Floor 3

Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height (m)
Hostel	1	44.8	10	2.5	5	2
Corridor	2	43	3.2	2.5	5	2
Foyer	3	35	9	2.5	5	2
Stair 1	4	7	3.4	10	0	9.5
Stair 2	5	7	3.4	10	0	9.5

Table 6.14: Geometry of vents as modeled in BRANZFIRE – Hostel fire on Floor 3

Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)
1 to 2	0.86	2	0	Door	Open	Always
1 to outside	0.055	2.5	0	Leakage	Open	Always
2 to 3	0.86	2	0	Fire door	Self-closing	34
2 to 4	0.44	2	0	Fire door	Self-closing	34
3 to 5	0.44	2	0	Fire door	Self-closing	34
3 to outside	0.017	2.5	0	Leakage	Open	Always
4 to outside	0.007	10	0	Leakage	Open	Always
5 to outside	0.003	10	0	Leakage	Open	Always

6.4.1.2 ASET Results

The BRANZFIRE modelling results are summarised in Table 6.15 for simulation time of 1800 s. The first column shows various fire locations applicable under DFS 1. The second column shows spaces of interest along the escape route from the room of fire origin until occupants away from firecell of fire origin. The third column shows the detection time by sprinkler. Columns 4 to 6 give the times that tenability criteria are reached, including FED CO, FED Thermal and Visibility. The last column summarises the ASET results. Visibility is the first criteria reached for all fire locations. However, as the building is fully sprinklered, only FED CO applies for occupant tenability. All safe path staircases remain tenable condition during the entire simulation.

Table 6.15: Summary of BRANZFIRE modelling results - Hospital

Location		Spaces	Detection Time (s)	Time to Reach Tenability Criteria (s)			ASET (s)
				FED CO = 0.3	FED Thermal = 0.3	Visibility = 10 m	
Floor 1	Cafeteria fire	Cafeteria	144 (SPK)	678	274	112	678
		Physiotherapy		>1800	>1800	1676	>1800
		Corridor 1		>1800	>1800	274	>1800
		Corridor 2		1650	>1800	230	1650
		Corridor 3		>1800	>1800	406	>1800
		Foyer		>1800	>1800	340	>1800
		Stair 1		>1800	>1800	>1800	>1800
		Stair 2		>1800	>1800	>1800	>1800
	Physiotherapy fire	Cafeteria	156 (SPK)	>1800	>1800	1631	>1800
		Physiotherapy		1029	449	156	1029
		Corridor 1		>1800	>1800	470	>1800
		Corridor 2		>1800	>1800	334	>1800
		Corridor 3		>1800	>1800	656	>1800
		Foyer		>1800	>1800	504	>1800
		Stair 1		>1800	>1800	>1800	>1800
		Stair 2		>1800	>1800	>1800	>1800
Floor 2	Lab fire	LAB	160 (SPK)	1186	604	187	1186
		Corridor		>1800	>1800	456	>1800
		Stair1		>1800	>1800	>1800	>1800
		Stair2		>1800	>1800	>1800	>1800
Floor 3	Hostel fire	Hostel	147 (SPK)	862	343	132	862
		Corridor		1431	>1800	268	1431
		Foyer		>1800	>1800	>1800	>1800
		Stair1		>1800	>1800	>1800	>1800
		Stair2		>1800	>1800	>1800	>1800

Key: SPK – Sprinklers

6.4.1.3 RSET Result

All occupants on the ground floor are considered to be awake at the time of the fire. At spaces which are opened to public, occupants are assumed to be unfamiliar with the building layout and possible escape routes. Occupants at Hostel on Floor 3 are considered sleeping and unfamiliar with the building. Patients at Chronic Care Unit, Cancer Care Unit, Surgical Unit and Maternity are considered sleeping and under the care of trained staff. The detection times are taken from BRANZFIRE modelling upon sprinkler activation. The RSET results are summarised in Table 6.16.

The proposed C/VM2 does not provided guidance on hospital evacuation. It has been noticed that C/VM2 gives a relative long pre-movement time for occupants under care which is 30 minutes. It is assumed that it already takes into account the time to prepare for moving patients and the egress calculation for patients are currently based on normal walking speed. However, readers shall refer to Section 6.8 for more detailed discussion on hospital evacuation and patient room fire scenario.

Table 6.16: RSET results for the hospital

Events	Time (s)
Floor 1 Cafeteria Fire	
Time to detection t_d	144s (SPK)
Time for pre-movement t_p	60s for Cafeteria (fire origin), Emergency, Staff rooms, Lab, Storage, Office Unit; 120s for Admitting, Imaging, Physiotherapy and Psychiatric; 600s for Hostel; 1800s for SC firecells
Time for travel / flow t_t	154s clear Cafeteria into corridor (queuing govern)
RSET for clear room of fire origin (Cafeteria)	= $t_d + t_p + t_t$ =144s+60s+154s=358s
RSET for clear firecell of fire origin (Floor 1)	= $t_d + t_p + t_t$ =144s+60s+173s=377s
Floor 1 Physiotherapy Fire	
Time to detection t_d	156s (SPK)
Time for pre-movement t_p	60s for Physiotherapy (fire origin), Lab, Storage Office Unit; 120s for Cafeteria, Admitting, Imaging and Psychiatric; 600s for Hostel; 1800s for SC firecells
Time for travel / flow t_t	41s clear Physiotherapy into corridor (walking govern)
RSET for clear room of fire origin (Physiotherpy)	= $t_d + t_p + t_t$ =156s+60s+41s=304s
RSET for clear firecell of fire origin (Floor 1)	= $t_d + t_p + t_t$ =156s+60s+233s=449s
Floor 2 Lab Fire	
Time to detection t_d	160s (SPK)
Time for pre-movement t_p	30s for Lab(fire origin); 60s for Storage, Staff rooms and Office Units; 120s for other non-sleeping spaces; 600s for Hostel; 1800s for SC firecells
Time for travel / flow t_t	61s clear Lab into corridor (walking govern)
RSET for clear room of fire origin (Lab)	= $t_d + t_p + t_t$ =160s+60s+61s=281s
RSET for clear firecell of fire origin	= $t_d + t_p + t_t$ =160s+60s+88s=308s
RSET for clear floor of fire origin (Floor 2)	= $t_d + t_p + t_t$ =160s+1800s+49s=2009s

(Continued…)

Events	Time (s)
Floor 3 Hostel Fire	
Time to detection t_d	147s (SPK)
Time for pre-movement t_p	60s for Hostel (fire origin), Storage, Lab, Staff rooms, Office unit ; 120s for other non-sleeping spaces; 1800s for SC firecells.
Time for travel / flow t_t	45s clear Hostel into corridor (walking govern)
RSET for clear room of fire origin (Hostel)	= $t_d + t_p + t_t$ =147s+60s+45s=252s
RSET for clear firecell of fire origin	= $t_d + t_p + t_t$ =147s+60s+65s=272s
RSET entire Floor3	= $t_d + t_p + t_t$ =147s+1800s+49s=1996s

6.4.1.4 RSET vs. ASET

Table 6.17 summarises the results for RSET versus ASET and the safety margin. The design will fail where RSET exceeds ASET. The results show the design meets the C/VM2 criteria with most critical fire location at Cafeteria on the ground floor.

Table 6.17: RSET vs. ASET results for the hospital

		Criteria	Time Reached (s)	Margin = ASET-RSET (s)
Floor 1 Cafeteria Fire	Room of fire origin (Cafeteria tenability)			
	RSET(Cafeteria)		358	-
	ASET	Visibility = 10 m	112	***-246*** (N/A)
	ASET	FED Thermal = 0.3	274	***-84*** (N/A)
	ASET	FED CO = 0.3	678	320
	Firecell of fire origin (Corridor tenability)			
	RSET(Floor1)		377	-
	ASET	Visibility = 10 m	230	***-147*** (N/A)
	ASET	FED Thermal = 0.3	>1800	>1423 (N/A)
	ASET	FED CO = 0.3	1650	1273
Floor 1 Physiotherapy Fire	Room of fire origin (Physiotherapy tenability)			
	RSET(Physiotherapy)		304	-
	ASET	Visibility = 10 m	156	***-148*** (N/A)
	ASET	FED Thermal = 0.3	449	145 (N/A)
	ASET	FED CO = 0.3	1029	725
	Firecell of fire origin (Corridor tenability)			
	RSET(Floor1)		449	-
	ASET	Visibility = 10 m	334	***-115*** (N/A)
	ASET	FED Thermal = 0.3	>1800	>1351 (N/A)
	ASET	FED CO = 0.3	>1800	>1351

(Continued…)

		Criteria	Time Reached (s)	Margin = ASET-RSET (s)
Floor 2 Lab Fire	Room of fire origin (Lab tenability)			
	RSET(Lab)		281	-
	ASET	Visibility = 10 m	187	***-94*** (N/A)
		FED Thermal = 0.3	604	323 (N/A)
		FED CO = 0.3	1186	905
	Firecell of Fire Origin (Corridor tenability)			
	RSET(North corridor)		308	-
	ASET	Visibility = 10 m	456	148 (N/A)
		FED Thermal = 0.3	>1800	>1492 (N/A)
		FED CO = 0.3	>1800	>1492
Floor 3 Hostel Fire	Room of fire origin (Hostel tenability)			
	RSET(Lab)		252	-
	ASET	Visibility = 10 m	132	***-120*** (N/A)
		FED Thermal = 0.3	343	91 (N/A)
		FED CO = 0.3	862	610
	Firecell of Fire Origin (Corridor tenability)			
	RSET(North corridor)		272	-
	ASET	Visibility = 10 m	268	***-4*** (N/A)
		FED Thermal = 0.3	>1800	>1528 (N/A)
		FED CO = 0.3	1431	1159

Values shown in ***bold italic*** *show that RSET exceeds the ASET* *N/A – Not applicable*

6.4.2 DFS 2 – Blocked Exit

Except that some spaces with occupant loads up to 50 have single escape routes from room origin, all other spaces with more than 50 occupants have at least two means of escape equally sized. Therefore with one blocked exit in each space still have at least 50 % of the required exit width available. Each floor level has more than two vertical safe paths. Therefore this scenario is achieved.

6.4.3 DFS 3 – Fire in Unoccupied Room

The fire safety features for the hospital building include a fully compliant sprinkler system installed throughout the building which satisfies this scenario.

6.4.4 DFS 4 – Fire in Concealed Space

The fire safety features for the hospital building include a fully compliant sprinkler system installed throughout the building which satisfies this scenario.

6.4.5 DFS 5 – Smouldering Fire

This scenario addresses the fire safety concern regarding a slow, smouldering fire that causes a threat to sleeping occupants. The expected methodology is to provide smoke detections. Based on previous prescriptive design, smoke detectors will be installed in all firecells containing sleeping occupants under care (SC firecells). However, the Hostel (SA firecell) only requires sprinkler system by C/AS1. To meet the proposed C/VM2, smoke detectors will be required in Hostel.

6.4.6 DFS 6 – Fire Spread to Other Property

The performance objective of this scenario is to prevent fire spread to neighboring buildings as a result of heat transfer. As the building is not beside any boundaries and this scenario does not apply.

6.4.7 DFS 7 – Vertical External Fire Spread

The building contains sleeping occupants on upper floors and this scenario applies. There are two parts to this scenario. For Part 1, the exterior claddings of external walls are assumed to be pre-cast concrete which have a peak heat release rate less than 100 kW/m^2 that flame spread over its surface is unlikely. It satisfies Performance Measure 1. For Part 2, the building is sprinkler protected and satisfies Performance Measure 2. Therefore, this scenario is achieved.

6.4.8 DFS 8 – Interior Surface Finishes

This scenario applies to all buildings except that the smoke production rate criterion is not required for sprinkler protected buildings. Hospitals (PG 4 buildings) are considered essential to post-disaster recovery and have more rigorous requirements for interior surface finishes. According to the proposed C/VM2, in all occupied spaces in PG 4 buildings, the surface finishes of walls and ceilings shall be Group 1 materials achieving a time to flashover not less than 20 minutes. Floor surfaces in safe paths will be concrete which is non-combustible. Smoke production rate criteria need not apply as the building is sprinkler protected.

6.4.9 DFS 9 – Fire Service Operations

As the building is fully sprinklered and the distance from the safe path access to any point on a floor does not exceed 75 m, firefighting tenability analysis is not required. To facilitate rapid size-up of the situation for firefighting, control panels indicating the status of fire safety systems will be installed in the building. Structural stability criteria for firefighters are achieved by providing fire resistance ratings that comply with C/AS1. To facilitate adequate firefighting water, based on the C/AS1 design, internal hydrant system will be provided on all floors and the building is fully sprinkler protected.

6.4.10 DFS 10 – Robustness Check

The objective of this scenario is to do a robustness check with each key fire safety system rendered in effective in turn, including fire doors in the hospital building. Fire sprinklers and automatic fire alarms complied with New Zealand Standard are considered to be sufficiently reliable.

It is rarely that all fire doors in a building are failed to remain their normal function at the same time. For this scenario, each fire door is rendered ineffective in turn. The ASET versus RSET analysis was carried out for fire in the Lab on Floor 2 with one fire door into Chronic Care rendered ineffective (modelled as open) as shown in Figure 6.12.

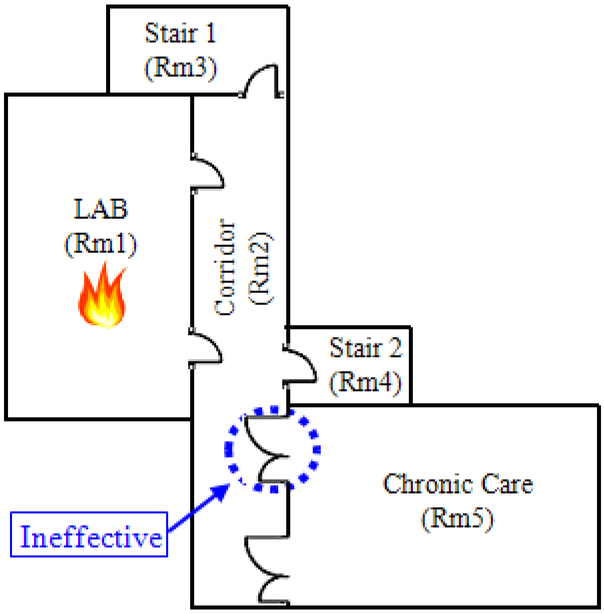


Figure 6.12:Fire door into Chronic Care rendered ineffective

The BRANZFIRE results show that the FED (CO) in Chronic Care does not reach 0.3 in the simulation time of 2500 s while occupants have cleared from this level at 2009 s. The design still meets the criteria.

6.5 Summary of Safety Margin for DFS 1

Fire protection systems include sprinklers throughout the building and smoke detectors in all patient sleeping areas. Only FED CO is provided here as the building is fully sprinklered. As shown in Figure 6.13 and Figure 6.14, the design meets the current C/VM2 with safety factor of 1.9. The most critical fire location is at Cafeteria on the ground floor.

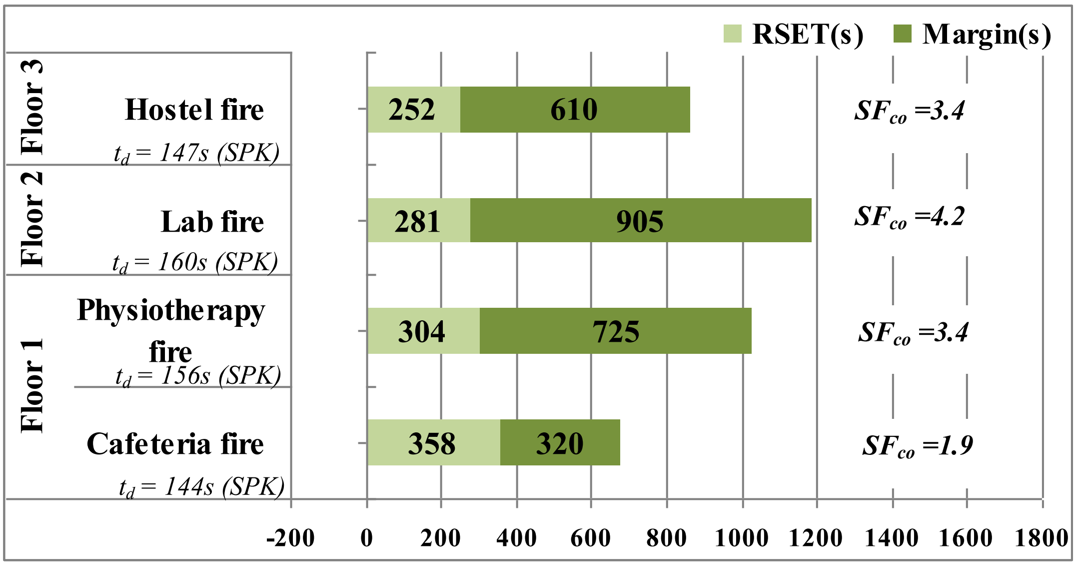


Figure 6.13: Hospital safety margin for room of fire origin

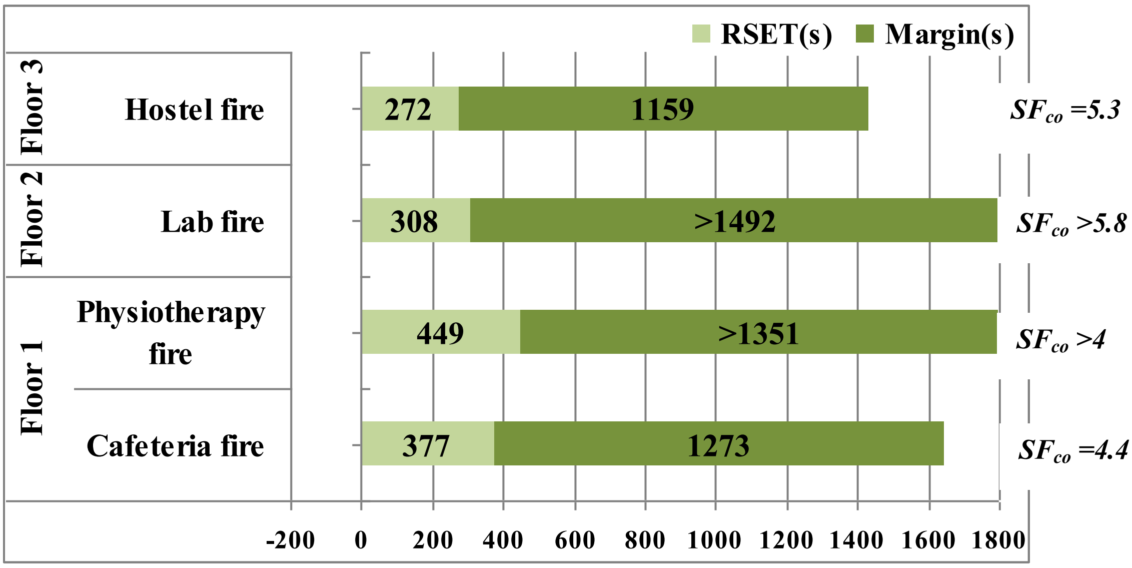


Figure 6.14: Hospital safety margin for firecell of fire origin

6.6 FDS vs. BRANZFIRE

In the hospital building, it is rarely smoke spreading to other floors via safe path staircases. Hence, only the floor of fire origin was modelled in FDS rather than the entire building considering its relatively large volume. Fire was located at the cafeteria on the ground floor and capped by sprinkler activation. The layout of the hospital ground floor in Smokeview is shown in Figure 6.15. The grid size in room of fire origin (Cafeteria) was 200 mm while 400 mm grid size was used in other spaces.

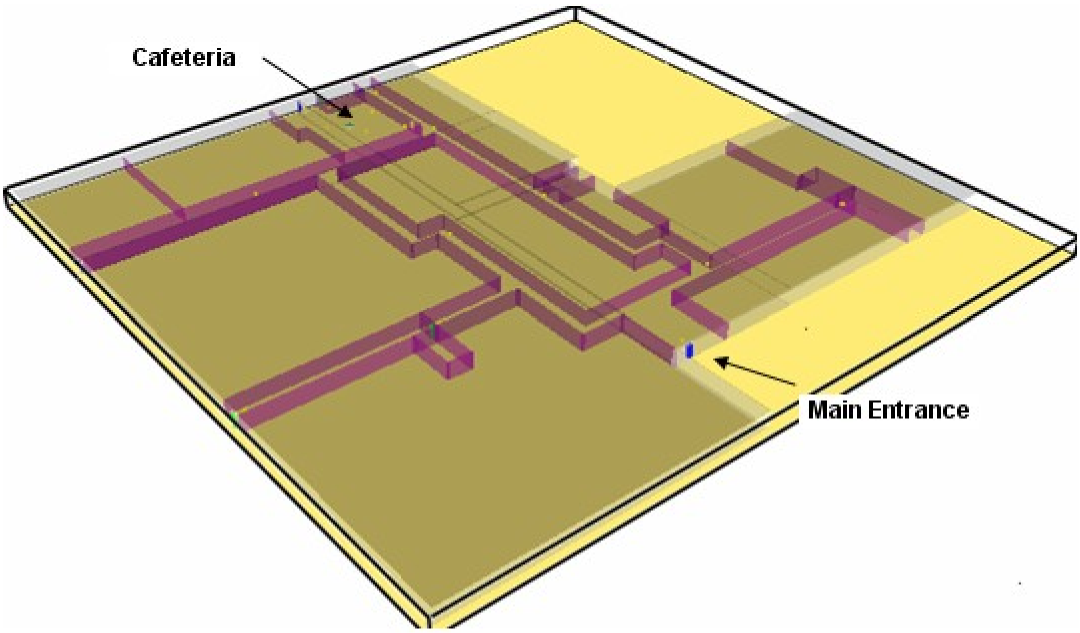
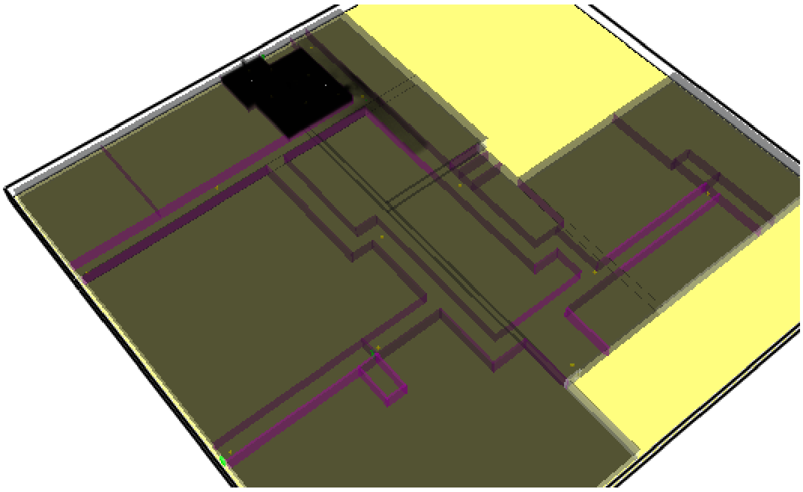
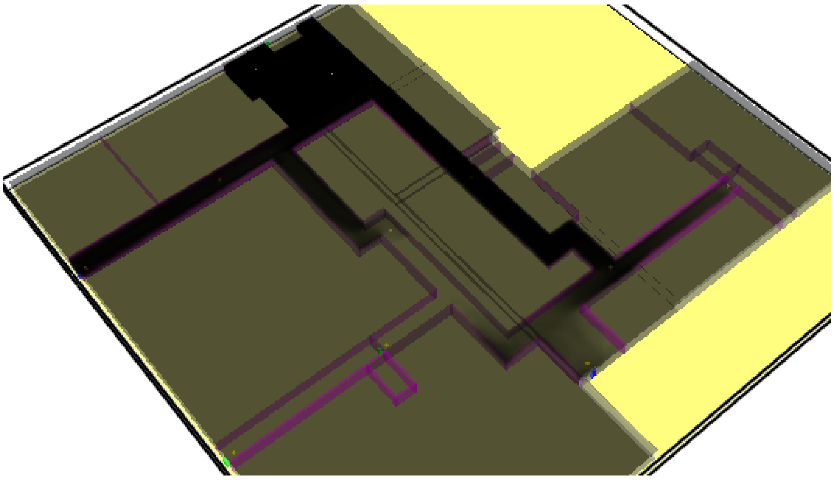


Figure 6.15: Hospital ground floor layout in Smokeview

Figure 6.16 shows the smoke development at t = 150 s & 500 s (elevation view from the south). At t = 150 s, smoke layer descends below 2 m in the Cafeteria and smoke starts to spread into the adjacent corridor, whilst at t = 500 s, smoke starts filling into the foyer by the main entrance.



(t=150s)



(t=500s)

Figure 6.16: Smoke development in FDS for fire at cafeteria in hospital

The results of FDS versus BRANZFIRE are summarised in Table 6.18. The FDS results are taken an average where there is more than one device in a space. The sprinkler activates at 142 s in FDS compared to 144 s in BRANZFIRE. The visibility in room of fire origin drops below 10 m much quicker in FDS than BRANZFIRE.

Table 6.18: BRANZFIRE vs. FDS for hospital – Ground floor cafeteria fire

	Criteria	Time Reached (s)		Difference (%)*
		BRANZFIRE	FDS	
Detection Time (s)	-	144 (SPK)	142 (SPK)	- 1
Room of fire origin (Cafeteria)	Visibility = 10 m	112	70	- 37.5
	FED Thermal = 0.3	274	333	21
	FED CO = 0.3	678	580	- 14.5
Firecell of fire origin (Ground corridor)	Visibility = 10 m	230	207	- 10
	FED Thermal = 0.3	>1800	>1800	-
	FED CO = 0.3	1650	1530	- 7

* *A negative value shows criteria is reached earlier in FDS than that in BRANZFIRE*

6.7 Discussion

As mentioned before, evacuation process of a hospital can be complicate. Different occupant characteristics and patient-to-staff ratios can result in different evacuation requirements. Because some patients are incapable of movement, they may require staff assistance for evacuation and spaces such as surgical theatres are required to remain functional in the event of fire. Patients in intensive care unit (ICU) are often connected to various life support devices, making movement very difficult and time-consuming. The proposed C/VM2 does not provide detailed guideline for the egress calculation for people with disability or under care, and the pre-movement times for patients in Table 3.10 are ambiguous.

On the other hand, under the prescriptive solution addressed before, where group sleeping area for patients is contained within one firecell, the number of beds shall not exceed 12, or 6 if the group sleeping area is sub-divided into suite such as rest homes for the elderly. The current C/VM2 does not have such compartmentation requirements.

Besides, the current Design Fire Scenario 1 only applies for room / space greater than 200 m^2 or with over 150 occupants. It may not apply to a building or a firecell if there is no room greater than 200 m^2 or with over 150 occupants. In the hospital, under the current DFS 1, the patient sleeping firecell does not require tenability analysis as there is no patient room greater than 200 m^2. However, fire in patient room is often the most fire concern in the design. Therefore, the suggestion is maybe at least one fire should be modelled in each firecell except for firecells of safe path or intermittent activity.

6.8 Patient Room Fire Analysis

Based on the above discussion, additional analysis is carried out for fire in the Chronic Care Unit on Floor 2. In accordance with the C/AS1 design, the sleeping area is sprinkler protected with smoke detectors for early warning. All patient room doors are modelled as open in BRANZFIRE. Two cases have been analysed: (1) The Chronic Care Unit contains more than 12 beds which shall be divided into two firecells in accordance with C/AS1. (2) The Chronic Care Unit is modelled without any compartmentation.

6.8.1 ASET – BRANZFIRE Modelling

6.8.1.1 With Compartmentation

Where a single firecell shall not contain over 12 beds in accordance to C/AS1, the unit is fire separated into two firecells. The geometry in BRANZFIRE is shown in Figure 6.17 including the corridor and foyer interconnecting nine patient rooms. Fire was located in one of the patient rooms. Room 2 containing three patient rooms was modelled as one space as well as Room 6. The geometry of rooms and details of vents are given in Table 6.19 and Table 6.20.

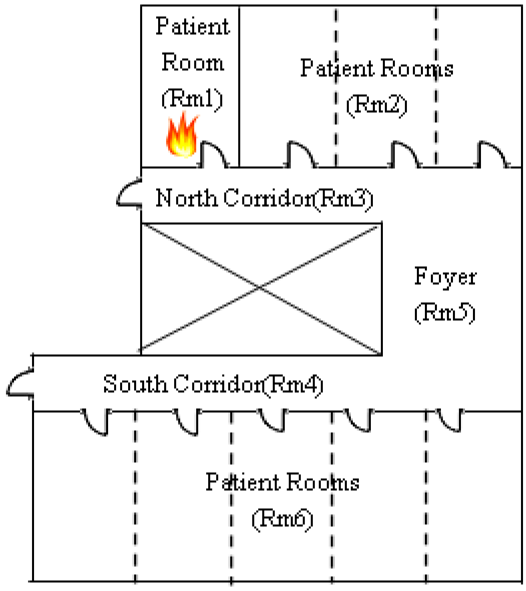


Figure 6.17: Geometry modelled in BRANZFIRE for patient room fire – with compartmentation

Table 6.19: Geometry of rooms in BRANZFIRE for patient room fire – with compartmentation

Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height(m)
Patient Room (fire orgin)	1	9	5	2.5	0	2
North Patient Rooms	2	15	9	2.5	0	2
North Corridor	3	13.4	3.2	2.5	0	2
South Corridor	4	18.4	3.2	2.5	0	2
Foyer	5	16.8	6.4	2.5	0	2
South Patient Rooms	6	25	9	2.5	0	2

Table 6.20: Geometry of vents as modeled in BRANZFIRE for patient room fire – with compartmentation

Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)
1 to 3	1.2	2	0	Door	open	Always
2 to 3	1.2	2	0	Door	open	Always
2 to 5	2.4	2	0	Door	open	Always
2 to outside	0.015	2.5	0	Leakage	open	Always
3 to outside	0.6	2	0	Fire door	Self-closing	12
3 to 5	3.2	2.5	0	Open wall	open	Always
4 to outside	0.6	2	0	Fire door	Self-closing	15
4 to 5	3.2	2.5	0	Open wall	open	Always
4 to 6	4.8	2	0	Door	open	Always
5 to 6	1.2	2	0	Door	open	Always
6 to outside	0.025	2.5	0	Leakage	open	Always

6.8.1.2 Without Compartmentation

In this case, there is no compartmentation to subdivide the area into two firecells. The geometry in BRANZFIRE is shown in Figure 6.18 including the corridor and foyer interconnecting total of fifteen patient rooms. Fire was located in one of the patient rooms. Room 2 containing six patient rooms was modelled as one space whilst Room 6 containing eight patient rooms was modelled as one space. The geometry of rooms and details of vents used in BRANZFIRE are given in Table 6.21 and Table 6.22.

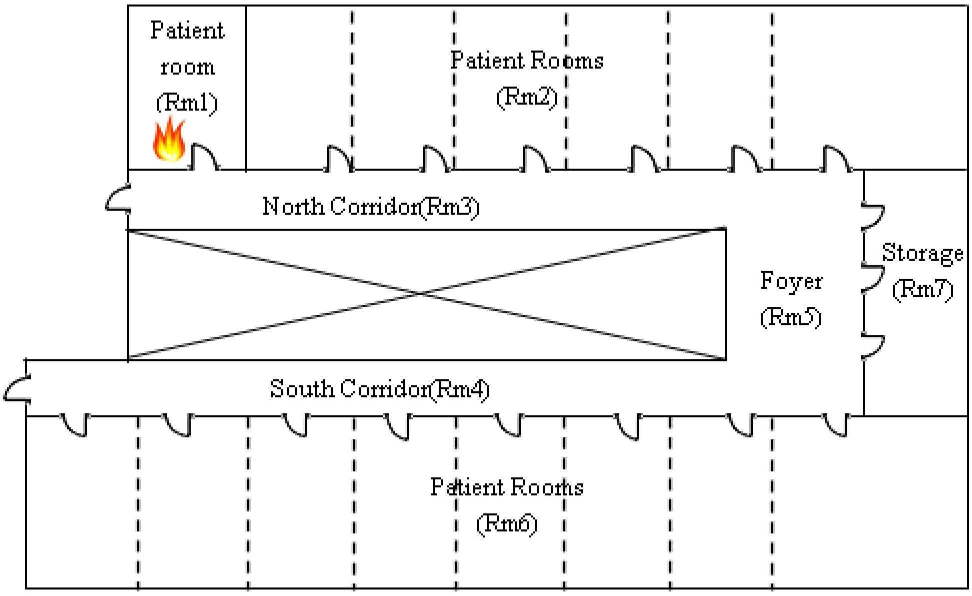


Figure 6.18: Geometry modelled in BRANZFIRE for patient room fire – without compartmentation

Table 6.21: Geometry of rooms in BRANZFIRE for patient room fire – without compartmentation

Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height(m)
Patient Room (fire origin)	1	9	5	2.5	0	2
North Patient Rooms	2	35	9	2.5	0	2
North Corridor	3	27.4	3.2	2.5	0	2
South Corridor	4	32.4	6	2.5	0	2
Foyer	5	16.8	6.4	2.5	0	2
South Patient Rooms	6	45	9	2.5	0	2
Storage	7	16.8	6	2.5	0	2

Table 6.22: Geometry of vents in BRANZFIRE for patient room fire – without compartmentation

Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)
1 to 3	1.2	2	0	Door	Open	Always
2 to 3	4.8	2	0	Door	Open	Always
2 to 5	2.4	2	0	Door	Open	Always
2 to outside	0.035	2.5	0	Leakage	Open	Always
3 to outside	0.6	2	0	Fire door	Self-closing	24
3 to 5	3.2	2.5	0	Open wall	Open	Always
4 to outside	0.6	2	0	Fire door	Self-closing	27
4 to 5	3.2	2.5	0	Open wall	Open	Always
4 to 6	7.2	2	0	Door	Open	Always
5 to 6	2.4	2	0	Door	Open	Always
5 to 7	3.6	2	0	Door	Open	Always
6 to outside	0.045	2.5	0	Leakage	Open	Always
7 to outside	0.017	2.5	0	Leakage	Open	Always

6.8.2 ASET Results

The ASET results are summarised in Table 6.23 for all three tenable criteria while only FED CO applies for sprinklered building. It has been noticed that patients are prone to toxic smoke than other occupants. It may not reasonable to have the same performance criteria as occupants who are not mentally or physically incapable. Hence, the value of 0.2 was used for the FED CO in this part of analysis.

The results show that FED CO in room of fire origin drops below 0.2 at 392 s. Where the unit is fire separated into two firecells, FED CO in the foyer drops below 0.2 at 964 s. A larger volume of smoke reservoir is expected when there is no subdivision of the unit that FED CO in the foyer drops below 0.2 at 1284 s.

Table 6.23: Summary of ASET results for patient room fire in hospital

Spaces		Detection Time (s)	Time to Reach Tenability Criteria (s)			ASET (s)
			FED CO = 0.2	FED Thermal = 0.3	Visibility = 5 m	
Patient Room (fire origin)		41 (SD)	392	144	45	392
With Compartmentation	Foyer		964	1499	108	964
Without Compartmentation	Foyer		1284	>1800	110	1284

6.8.3 RSET Analysis

Several questions as follows need to be answered before detailed analysis carried out. (*This part of report is only provided as an example. More detailed values used in the design shall comply with relative District Health regulations.*)

- What is the response time for the staff;
- How can the patients be moved and how fast each patient be moved;
- What is the patient-to-staff ratios during the day and night for different patient acuity;
- What is the minimum acceptable level of safety;
- Whether consider staff assisting evacuation from other wards;

6.8.3.1 Patient-to-staff Ratios

Values for patient-to-staff ratios can vary depending on the different time shifts (e.g. day time or night time), or acuity of patients. Lower patient-to-staff ratios are expected in department where patients require intensive care. Table 6.24 provides a reference for patient-to-staff ratios across different hospital departments in several countries.

Table 6.24: References for patient to staff ratios

References	**Patient to Staff Ratio**			
	ICU	Emergency	Surgical Unit	Medical Unit
Canterbury District Health Board, NZ[65]	2:1	-	4:1	5:1
Australia (Victoria)[65]	-	-	4:1 (am) 5:1(pm) 8:1(night)	
US Legislation (California) [65]	2:1	4:1	5:1	
	Critical	High risk	Stable	Minor
J Lawless (College of Emergency Nurses NZ) [66]	1:3	2:1	3:1	4:1

6.8.3.2 Some Literature Review

The literature on hospital evacuations primarily focuses on the evacuation of an entire hospital following a large scale natural event such as earthquake etc. Gildea J R and Etengoff S (2005)[67] carried out study on vertical evacuation of critically ill patients in a hospital. The results showed that a four firefighter extraction team as well as a accompanying nurse and respiratory therapist would be able to evacuate one patient at a rate of 3.75 minutes per floor.

The complexity and severity of intensive care unit (ICU) patients require additional consideration during an evacuation. Manion P and Golden J (2004) [68] have done study on vertical evacuation of an ICU unit. To prepare for evacuation, each patient had oxygen and was being ventilated with a bag-valve-mask as needed. The nurses attached the patient to portable oxygen and the oxygen tank was placed between the patient's legs. They placed the backboard on the bed, rolled the patients onto the backboard, and then lifted the backboard to the stretcher on the floor. The time required preparing the patient for vertical evacuation ranged from 3 to 8 minutes, and a team of 6 to 7 people was required with 4 carrying the stretcher, one overviewing the scene, one registered nurse and one physician if needed.

Burgess J L (1997) [69] have done a survey on evacuations in ten Washington State hospitals. The survey results are described in Table 6.25. The average time to move a patient in Intensive Care Unit (ICU) is 22 minutes and time to move a patient in Emergency Department (ED) is 8 to 9 minutes.

Table 6.25: Survey of 10 hospital evacuations in Emergency Department (Burgess 1997)

Location	Chemical	Source	Exposure	Duration (h)	Patients Moved	Staff Affected	Staff Symptoms	Duration Symptoms	Staff Treated	Closure Decision	Opening Decision
1 Med/surg, ICU	Picric acid	Spill	None	10	27	?	None	—	0	Hazmat team	Hazmat team
2 ED	Unknown	Contaminated patient	Inhalation	7.5	3	6	Nausea, MM irritation	Variable	5	Hazmat team	Hazmat team
3 ED and part of hospital	Explosives	Buried	None	7	50	?	None	—	0	Hospital commander	Hospital commander
4 ED	Cleaners	Regular use	Inhalation	4.5	2	4	Burning eyes, HA	15 min	0	Nursing supervisor	Nursing supervisor
5 ED	Exhaust	Air contamination	Inhalation	3	20	10	Nausea, HA	2 h	0	ED staff	ED staff
6 Central services	Ethylene oxide	Airborne release	None	2	0	5	None	—	0	Shift supervisor	Hospital supervisor
7 Endoscopy	Glutaraldehyde	Spill	Inhalation	2	2	6	Burning eyes, HA	Unknown	0	Hospital personnel	Hospital personnel
8 ED	Petroleum production	Contaminated patient	Inhalation	2	0	4	MM irritation, HA	2 h	0	ED staff	ED staff and Hazmat team
9 ED	Formalin	Spill	Inhalation	2	0	3	Nausea, HA	<1 h	1	Hospital staff, Hazmat team	Hospital staff, Hazmat team
10 Kitchen	Cleaners	Regular use	Inhalation	1	0	15	Nausea, LOC, HA	Variable	15	Hospital staff	Hazmat team
11 ED	Pepper spray	Airborne release	Inhalation	1	3	5	Burning eyes	<1 h	0	ED staff	ED staff

In the fire safety design for life safety the interest is often in the early fire development where the patients may require horizontal evacuation to an adjacent firecell. Frantzich H (1996) [70] provided a guideline for egress analysis of a health care facility shown in Figure 6.19. The maximum travel distance along the corridor is 30 m. The ceiling height is 3 m. Each patient room is 5 m wide by 6 m deep. All doors are 1.2 m wide. One exit in the corridor was considered blocked.

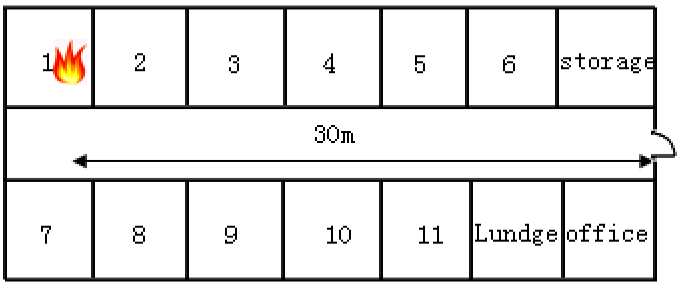


Figure 6.19: Geometry of a health care facility (Frantzich 1996)

The experiment results are provided as shown in Table 6.26. The variable t_{care} (s) is defined as the time by the staff in preparing a patient for movement, e.g. unplug life supporting devices etc.; t_t (s) is the movement time in corridor defined as the time spent in moving a patient from the door of the patient room to a point of safety outside the ward and the time occupied by the staff to reach the next patient. The staff response time is set relatively low as they are trained to respond to various kinds of signals. After the response phase, the staff will move towards the first patient. t_{1st} (s) is defined as the time occupied by the staff to reach the first patient after response time.

Table 6.26: Reference of travel time for a health care facility (Frantzich 1996)

Condition						
Awake/asleep	Awake	Awake	Awake	Asleep	Asleep	Asleep
Need of help	No	A little	Much	No	A little	Much
t_{care} (s)	5±5	10±5	15±5	10±3	20±5	30±10
t_t (s)	20±5	30±30	40±40	20±5	40±30	50±30
t_p (s) staff response time	10±3					
t_{1st} (s) time staff reach 1st patient	20±10 (daytime) 30±10 (nighttime)					

For occupants need much help for evacuation, the mean value of the travel time is 50 s and the average travel distance to move a patient out of the ward is 30 m including distance travelled by the staff to reach the next patient, then the average travel speed for moving a patient is 0.6 m/s. The ASET can be calculated using the following equations.

(1) RSET for clear room of fire origin:

$$RSET = t_d + t_p + t_{1st} + t_{care} \quad (6.1)$$

(2) RSET for clear the ward

$$RSET = t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot \text{patient-to-staff ratio} \quad (6.2)$$

6.8.3.3 RSET Results

The RSET calculations were based on the assumption that patients are incapable of self-evacuation and followed the guideline by Frantzich H (1996)[70]. The travel speed for moving a patient is 0.6 m/s. The patient-to-staff ratios vary from 1:1 to 1:10 as reference. The staff response time of 30 s was used as per proposed C/VM2.

Where the Chronic Care Unit is fire separated into two firecells in accordance with C/AS1 that a single group sleeping firecell shall not contain more than 12 beds, the RSET results are summarised in Table 6.27. Smoke detector was triggered 41 s in BRANZFIRE modelling. It takes 30 s for staff to respond to the alarm. The average travel distance to move a patient to adjacent firecell is 43 m including distance travelled by staff to reach the next patient. Based on a travel speed of 0.6 m/s, it takes 72 s to move a patient to the adjacent firecell. Where there is no fire separation to divide the Chronic Care Unit into two firecells, the RSET results are summarised in Table 6.28. A longer travel distance of 86 m is required to move a patient out of the ward.

Table 6.27: RSET results for fire in Chronic Care – with compartmentation

Events	Patient to Staff Ratio	RSET (s)
Time to detection: t_d (s)	41 (SD)	
Time for pre-movement: t_p (s)	30	
Time staff reach 1st patient t_{1st} (s)	30±10	
Average travel distance to move a patient (m)	43 (based on building plan)	
Time for travel : t_t (s)	43 / 0.6 = 72	
Time preparing patient for movement: t_{care} (s)	30±10	
RSET for clear room of fire origin	$t_d + t_p + t_{1st} + t_{care}$ = 41+30+(30±10)+(30±10) = 131±20	
RSET for clear firecell of fire origin	1:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 1$ = 41+30+(30±10)+(30±10+72) ·1 = 203±20
	2:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 2$ = 41+30+(30±10)+(30±10+72) ·2 = 305±30
	3:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 3$ = 41+30+(30±10)+(30±10+72) ·3 = 407±40
	4:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 4$ = 41+30+(30±10)+(30±10+72) ·4 = 509±50
	5:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 5$ = 41+30+(30±10)+(30±10+72) ·5 = 611±60
	6:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 6$ = 41+30+(30±10)+(30±10+72) ·6 = 713±70
	7:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 7$ = 41+30+(30±10)+(30±10+72) ·7 = 815±80
	8:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 8$ = 41+30+(30±10)+(30±10+72) ·8 = 917±90
	9:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 9$ = 41+30+(30±10)+(30±10+72) ·9 = 1019±100
	10:1	$t_d + t_p + t_{1st} + (t_{care} + t_t)\cdot 10$ = 41+30+(30±10)+(30±10+72) ·10 = 1121±110

Table 6.28: RSET results for fire in Chronic Care – without compartmentation

Events	Patient to Staff Ratios	Time (s)
Time to detection: t_d (s)	41 (SD)	
Time for pre-movement: t_p (s)	30	
Time staff reach 1st patient (s)	30±10	
Average travel distance to move a patient (m)	86 (based on building plan)	
Time for travel : t_t (s)	86 / 0.6 = 144	
Time preparing patient for movement: t_{care} (s)	30±10	
RSET for clear room of fire origin	$t_d + t_p + t_{1st} + t_{care}$ = 41+30+(30±10)+(30±10) = 131±20	
RSET for clear firecell of fire origin	1:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 1$ = 41+30+(30±10)+(30±10+144) ·1 = 275±20
	2:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 2$ = 41+30+(30±10)+(30±10+144) ·2 = 449±30
	3:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 3$ = 41+30+(30±10)+(30±10+144) ·3 = 623±40
	4:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 4$ = 41+30+(30±10)+(30±10+144) ·4 = 797±50
	5:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 5$ = 41+30+(30±10)+(30±10+144) ·5 = 971±60
	6:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 6$ = 41+30+(30±10)+(30±10+144) ·6 = 1145±70
	7:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 7$ = 41+30+(30±10)+(30±10+144) ·7 = 1319±80
	8:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 8$ = 41+30+(30±10)+(30±10+144) ·8 = 1493±90
	9:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 9$ = 41+30+(30±10)+(30±10+144) ·9 = 1667±100
	10:1	$t_d + t_p + t_{1st} + (t_{care} + t_t) \cdot 10$ = 41+30+(30±10)+(30±10+144) ·10 = 1841±110

6.8.3.4 RSET vs. ASET

Table 6.29 provides a summary of RSET vs. ASET results for a patient room fire. Only FED CO applies for tenability criteria. The results show that where the patient-to-staff ratio is less than 4:1 that there are sufficient staff to give assistance for evacuation, both cases can achieve a safety factor of 2.0 and it is not necessarily to divide the space into two firecells. At patient-to-staff ratio of 4:1, the space must be divided into two firecells to achieve a safety factor for FED CO of 2.0. Where patient-to-staff ratio is greater than 8:1, both cases cannot achieve safety factor of 1.0 and fail to meet the criteria as there are insufficient staff available for evacuation. However, it is rarely to have such low staff-patient-ratio for departments such as ICU or Emergency Department, where occupants require intensive care and incapable of evacuation. Also, it is more likely staff in adjacent firecells will assist in evacuation which was not counted into the above analysis.

Table 6.29: RSET vs. ASET results for patient room fire in Chronic Care

	Patient to Staff Ratio	**With Compartmentation**			**Without Comartmentation**		
		ASET(s)	**RSET(s)**	**SF**	**ASET(s)**	**RSET(s)**	**SF**
Room of fire origin	-	392	131±20	3.0±0.4	-	-	-
Firecell of fire origin	1:1	964	203±20	4.8±0.4	1284	275±20	4.7±0.3
	2:1		305±30	3.2±0.3		449±30	2.9±0.2
	3:1		407±40	2.4±0.2		623±40	2.1±0.2
	4:1		509±50	1.9±0.2		797±50	1.6±0.2
	5:1		611±60	1.6±0.2		971±60	1.3±0.1
	6:1		713±70	1.35±0.15		1145±70	1.1±0.05
	7:1		815±80	1.2±0.1		1319±80	1.0±0.05
	8:1		917±90	1.05±0.1		1493±90	0.85±0.0
	9:1		1019±100	0.95±0.1		1667±100	0.8±0.04
	10:1		1121±110	0.85±0.1		1841±110	0.7±0.04

Key: SF – Safety factor

6.8.3.5 FDS vs. BRANZFIRE – Patient Room Fire

The graphic layout of the Chronic Care Unit on Floor 2 in Smokeview is shown in Figure 6.20. All patient room doors, which are non-fire rated doors, were modelled as fully open. Fire was located in one of the patient room and capped by sprinkler activation. A grid size of 200 mm was used.

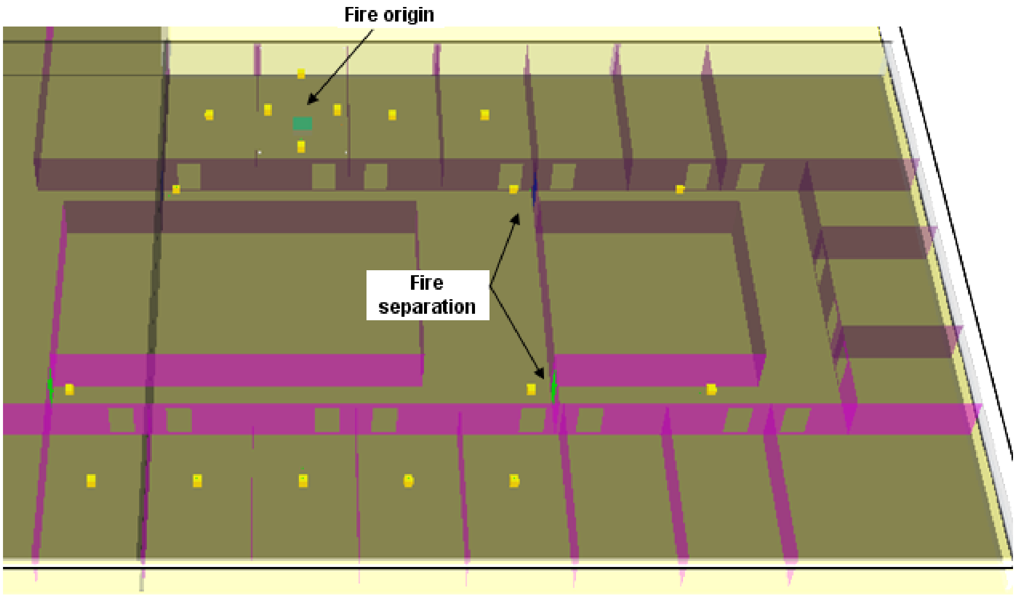


Figure 6.20: Layout of Chronic Care Unit in Smokeview

The results of FDS versus BRANZFIRE are summarised in Table 6.30 where the Chronic Care Unit was modelled both as two firecells or a single firecell. The location of devices as well as plots at each location are provided in APPENDIX L–4 (with compartmentation) and APPENDIX L–5 (without compartmentation).

Table 6.30: BRANZFIRE vs. FDS for hospital – Patient room fire

	Criteria	Time Reached (s)					
		With Compartmentation			Without Compartmentation		
		BF	FDS	Difference (%)	BF	FDS	Difference (%)
Detection Time (s)	-	41 (SD)	46 (SD)	12%	-	-	-
Room of fire origin	Visibility =5m	45	50	11%	-	-	-
	FED Thermal =0.3	144	163	13%	-	-	-
	FED CO =0.2	392	354	- 10%	-	-	-
Firecell of fire origin	Visibility =10m	108	83	- 23%	110	83	- 24.5%
	FED Thermal =0.3	1499	1267	- 15%	>1800	>1800	-
	FED CO =0.2	964	724	- 25%	1284	1087	- 15%

* *A negative value shows criteria is reached earlier in FDS than that in BRANZFIRE (BF)*

CHAPTER 7 CASE STUDY 3 - SHOPPING MALL

7.1 Introduction

It is recognized that both life safety and property protection are of importance in shopping mall buildings[71]. The problems with shopping malls are that they are complex and the architecture is unconventional. They can be single or multiple storeys and often incorporate large atria using modern architectural designs and new materials. Shopping malls are also complex in use that are designed to accommodate various stores including supermarkets, large clothes shops, book shops, toy shops and sport store etc. Walls between the mall stores are often partition walls, a flexibility that permits increasing or decreasing the size of the stores, which introduce large fuel loads and contribute to rapid fire spread[72]. Nowadays, shopping malls are no longer places where people only come for shopping, but also for entertainment. Mall owners are acutely aware of this and strive to lure crowds to their facilities with game arcades, cinemas as well as food courts, bars and restaurants. Some shopping malls are even part of a hotel complex or transit terminals.

In accordance with the above nature of a shopping mall, it poses a particular high risk in the event of fire. In 1977, a quarter of the Westgate Mall in Bethlehem, USA burned down. In 1981, Pennsylvania shopping centre, USA was destroyed by arson on Christmas Eve[72]. In 1983, fire in the Brunswick Mall, Germany resulted in the entire area from total destruction to heavy smoke and heat damage estimated at $7 to 8 million to the building and $4 million to contents[73]. More recently, in 2001, a debris fire at the rear of a shopping plaza in Phoenix, USA resulted in the death of a firefighter and several others injured[74]. In 2009, fire in one of the largest shopping centers in the Bangladeshi, Dhaka resulted in at least one person killed and 17 injured[75].

Fire protection philosophies in shopping mall often involve automatic sprinkler system which has proven to be an effective means to preserve human life and property protection[76]. The effectiveness of sprinklers controlling a fire is questioned in the atrium space due to the height. Other fire protection strategies should be employed such as smoke control system since smoke-related injuries and deaths outnumber fire-related injuries and deaths[72]. Detectors are provided for early warning with long path beam smoke detectors in large atria spaces. A ring signal may not be sufficient to get the attention of shoppers that a voice message is recommended. To help occupants making their way out of the building, exit signs should be clear and unambiguous with emergency battery back-up in case of power failure.

7.2 Design Specifications

The shopping mall to be analysed in this chapter is taken from the case study on the 2000 SFPE 3rd International Conference on Performance-Based Codes and Fire Safety Design Methods[3]. It shall be built according to the building plans in Figure 7.1 and Figure 7.4 having the following specifications:

- The facades positions are fixed and cannot be moved or changed;
- Inside the building there shall be one atrium centrally located according to the plans;
- The suggested positions of the shops can be moved but there shall be some kind of walkway where the customers can walk around outside the shops;
- The building shall contain the following sizes and number of shops which can be used for selling clothes, electronics, cosmetics, provisions, books, and liquor etc.

  Four large size shops (2000 – 3500 m^2)

  Twenty medium size shops (600 – 1300 m^2)

  Twenty small size shops (100 – 300 m^2)
- There shall be parking areas as specified on the building plans, however, small adjustments in the layout are allowed. The changes can for example be due to extra staircases;
- The building should contain two restaurants, one on floor 2 and one on floor 3. Each of the restaurants shall have seating for 200 people;
- In the atrium space there shall be a food court with seating for 50 people at each of floor 2 & 3.

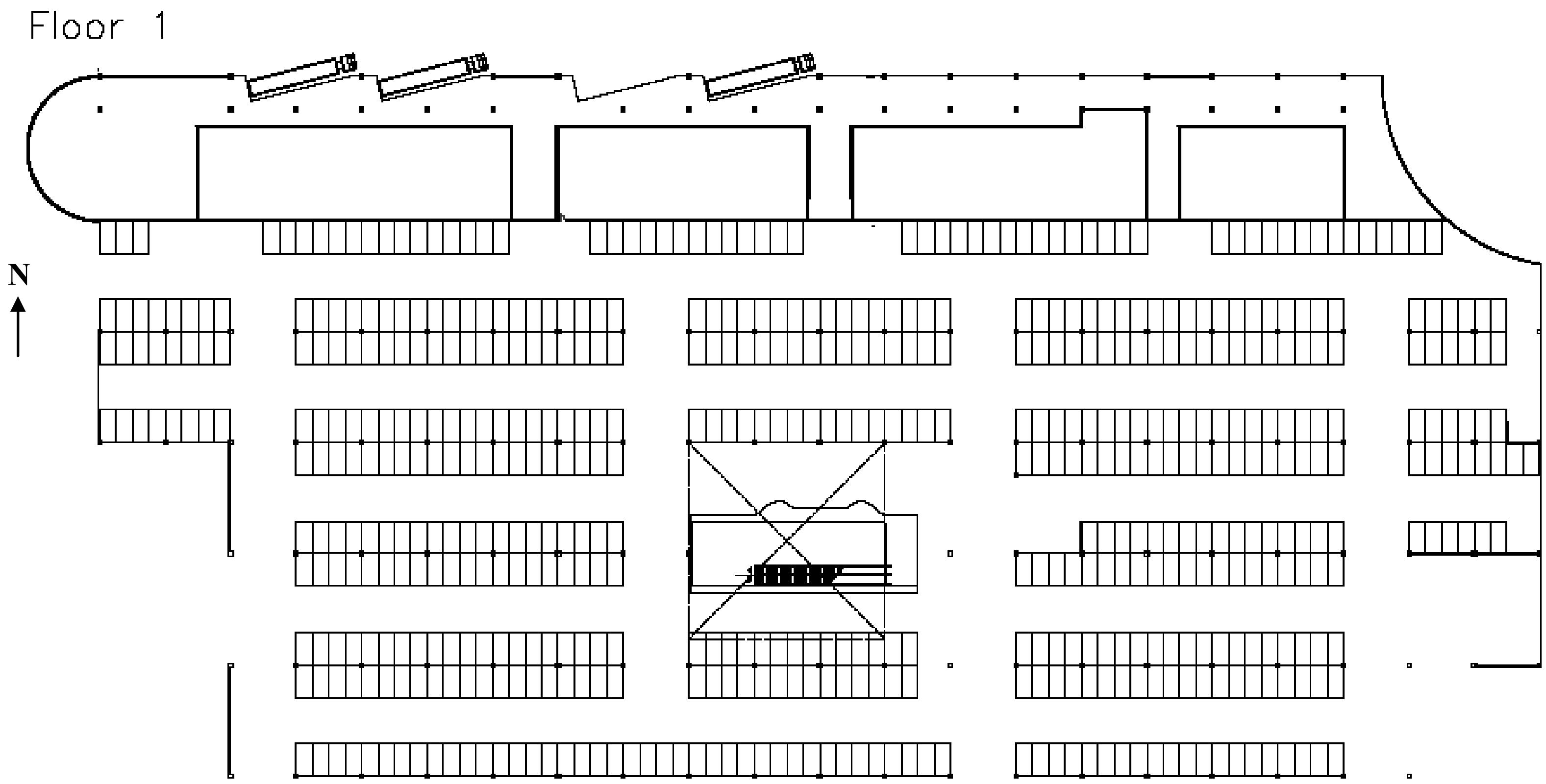


Figure 7.1: Original Shopping Mall Building Plan – Floor 1 (Ground Floor)

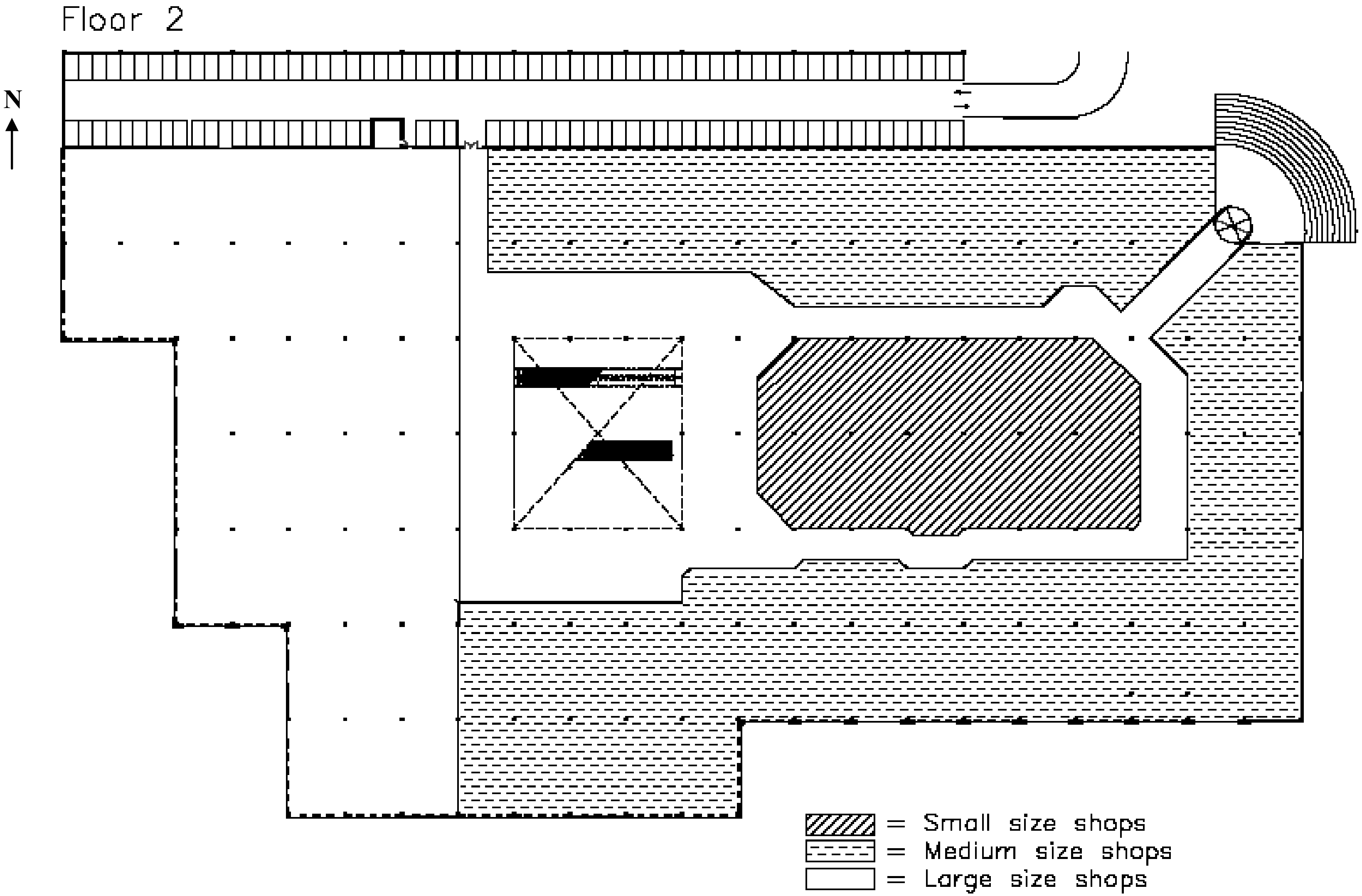


Figure 7.2: Original Shopping Mall Building Plan – Floor 2

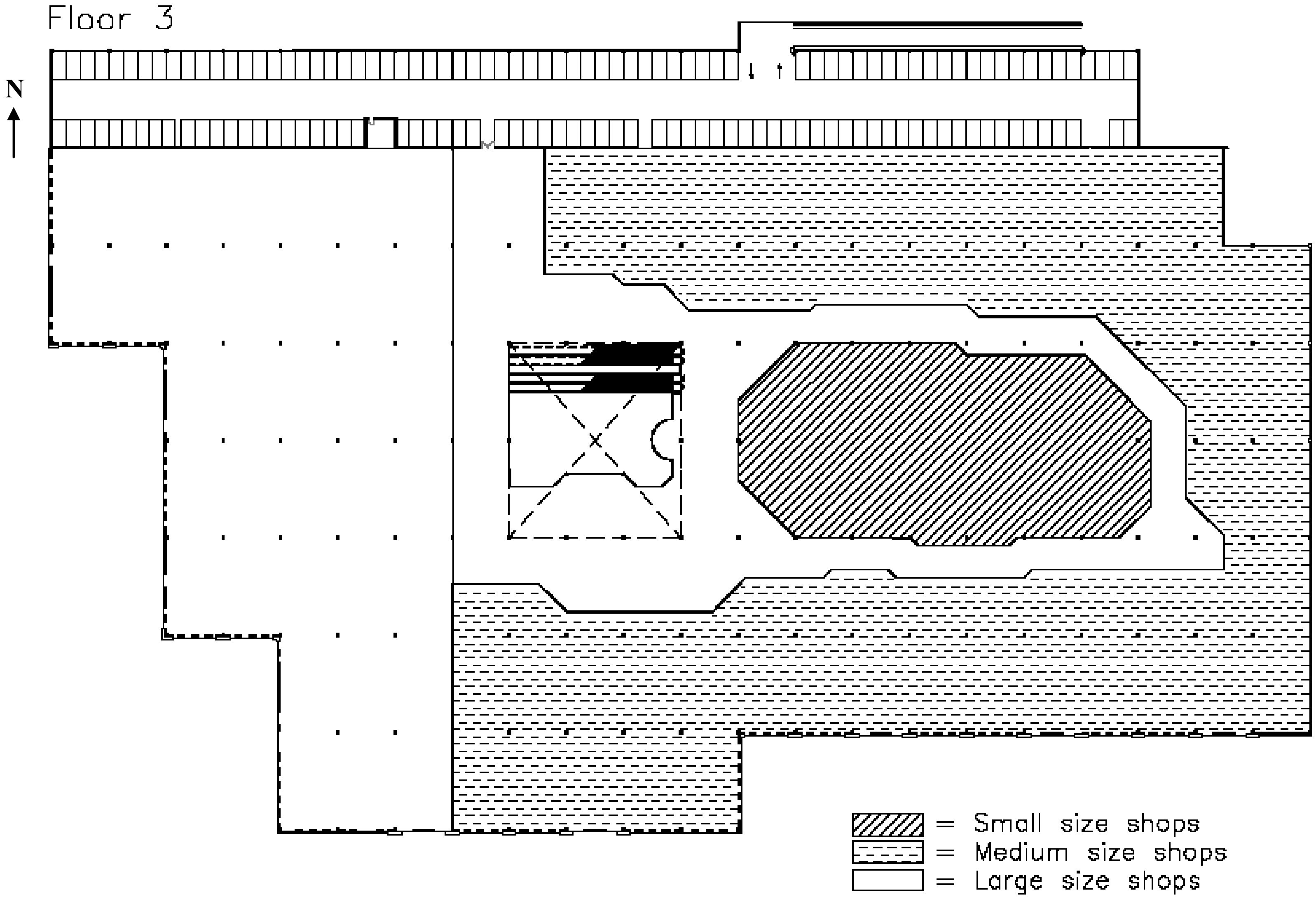


Figure 7.3: Original Shopping Mall Building Plan – Floor 3

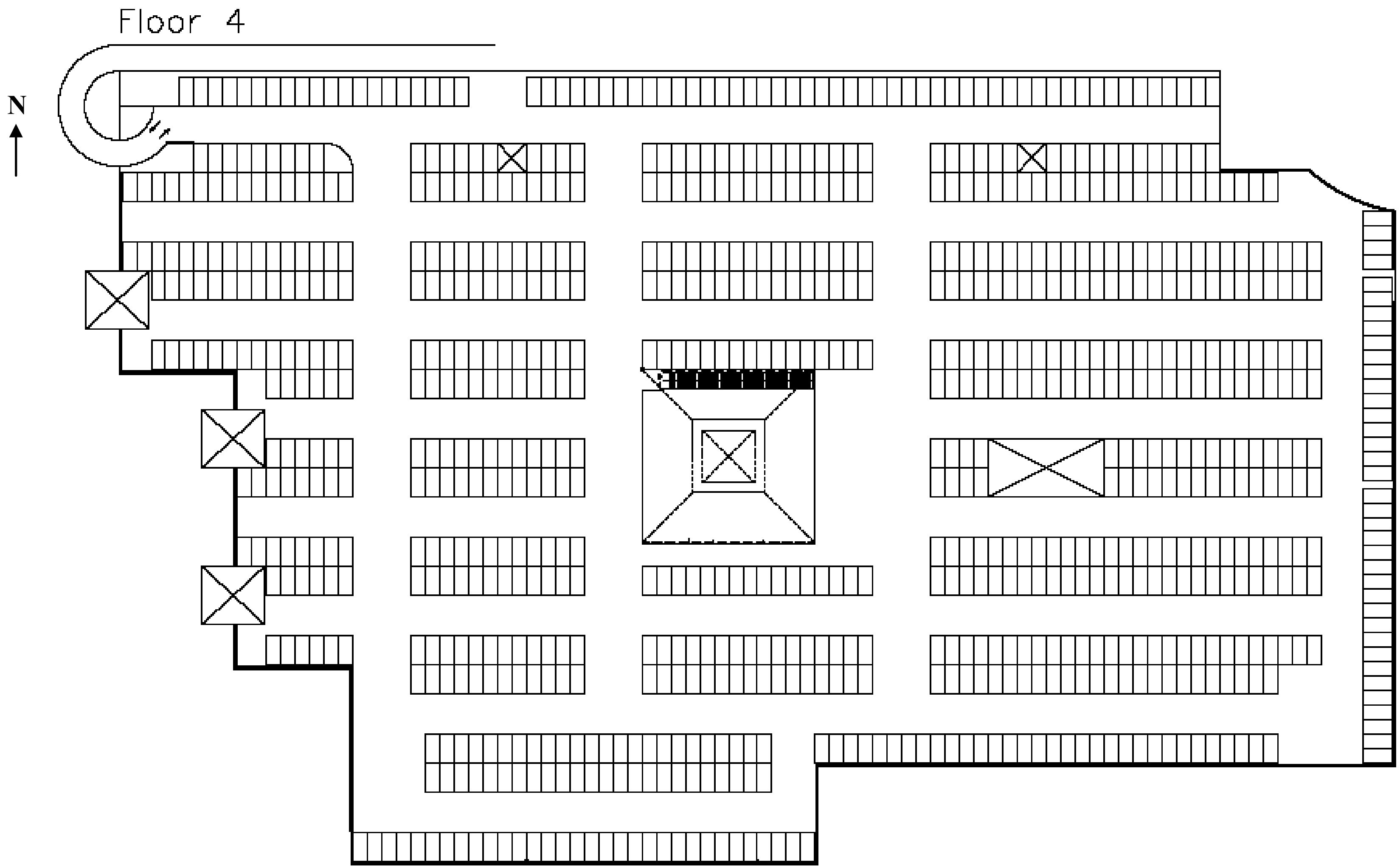


Figure 7.4: Original Shopping Mall Building Plan – Floor 4

7.3 Building Description

The premise is a four-storey complex shopping centre and can be accessed by the two main entrances on Floor 2 via external stairs from the ground floor. According to the design specifications, the building is adjusted with one extra main entrance at the west and six internal staircases as shown in Figure 7.5 and Figure 7.8 to provide sufficient means of egress for the full occupant loads in accordance with C/AS1.

The ground floor (Floor 1) contains storage areas with truck access, carparking area, and access to escalators, lift and stairs which provide access to the upper floors.

Floors 2 and 3 contain retail tenancies and are connected by a central atrium. Each floor contains a restaurant by the northeast main entrance, which has seating for two hundred people. There is a food court, with seating for fifty people, in the atrium space on each floor. Egress from retail floors can be either via two main entrances connected to external stairways shown by the solid red arrows, or via the internal staircases as shown by the dotted green arrows.

The roof (Floor 4) contains car parking, lift machine rooms, and access to escalators, stairs and lifts. Activities on this floor are intermittent. Egress from the roof can be via six internal staircases.

It is assumed that the ceiling height on the ground floor is 2.4 m, and 4.5 m on all upper floors. The rack height in the storage firecell is 2.0 m. The atrium extends 3.0 m above the roof car park level. Three areas of toilets have been provided on Floors 2 and 3, the retail floors. Four lifts, two in retail space and two in carprking area, have been allowed to provide access between floors.

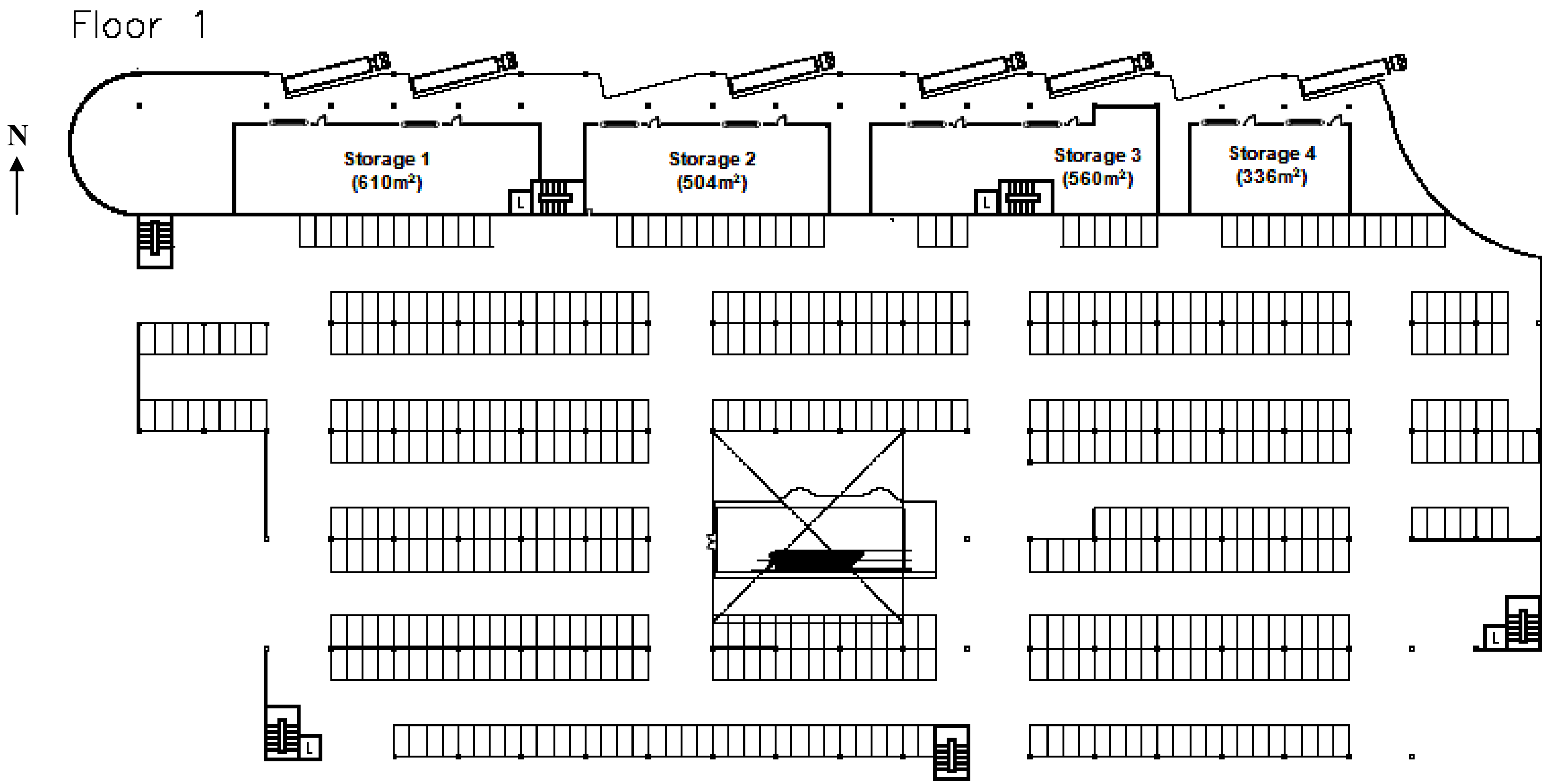


Figure 7.5: Designed Shopping Mall Building Plan – Floor 1 (Ground Floor)

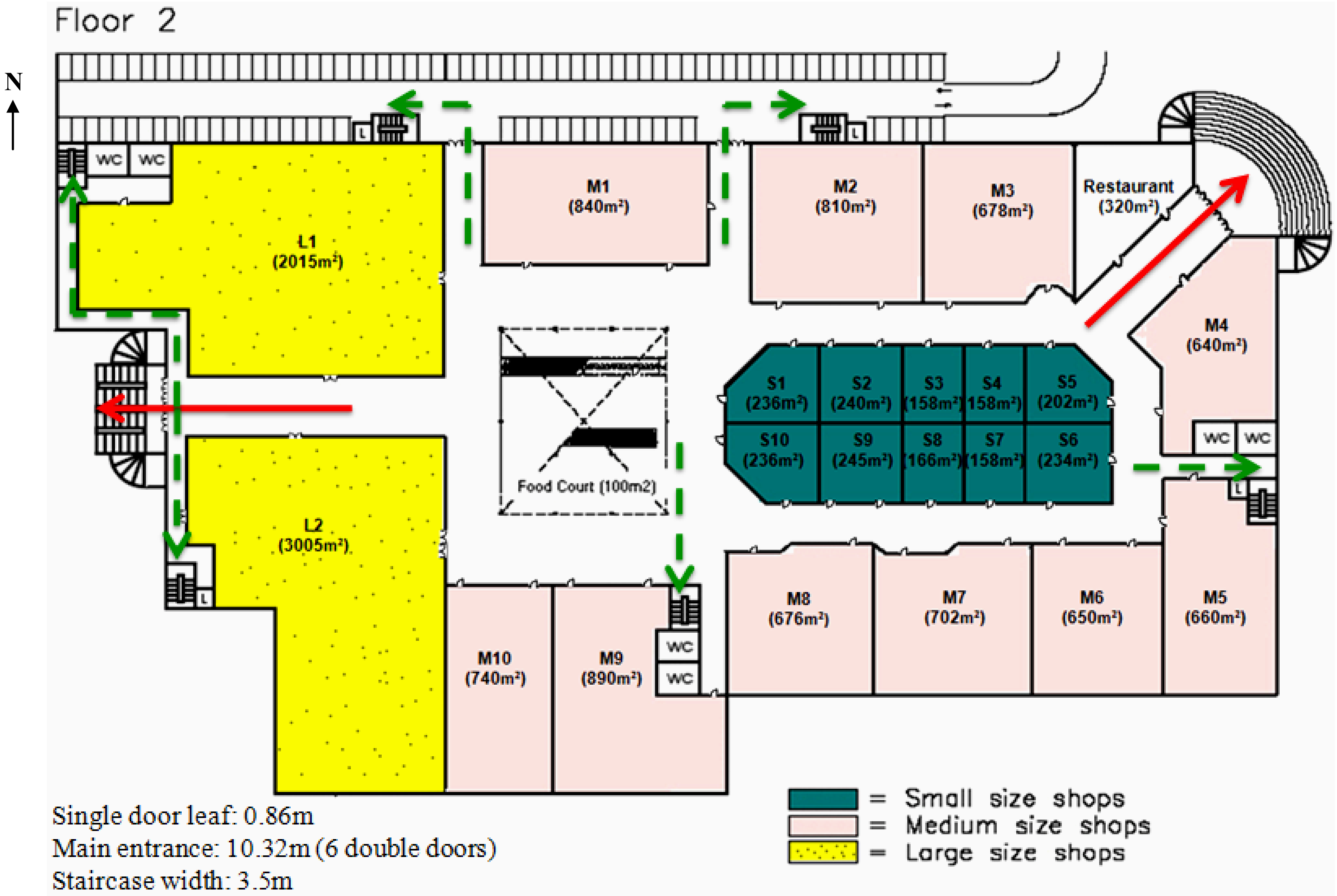


Figure 7.6: Designed Shopping Mall Building Plan – Floor 2

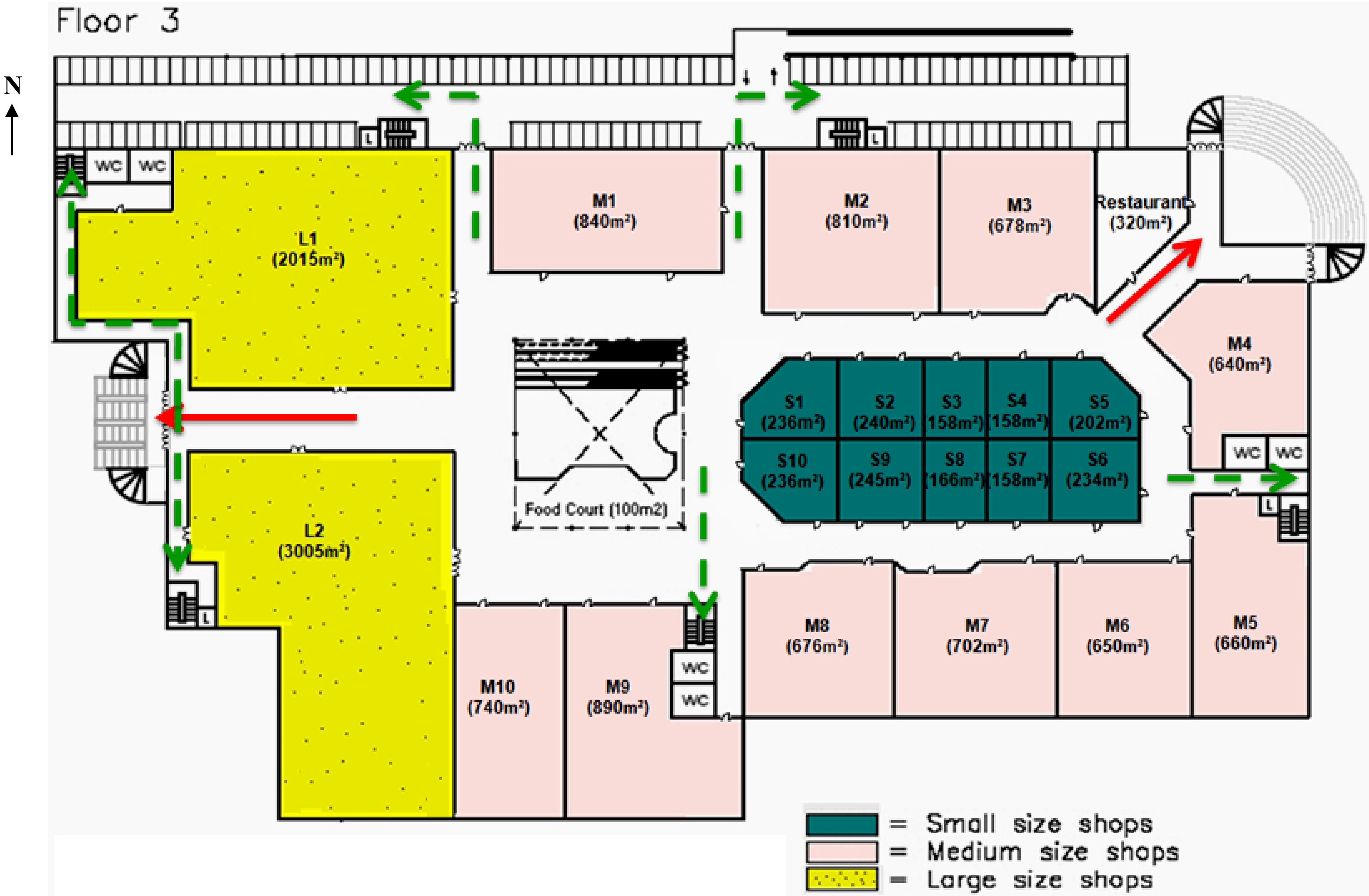


Figure 7.7: Designed Shopping Mall Building Plan – Floor 3

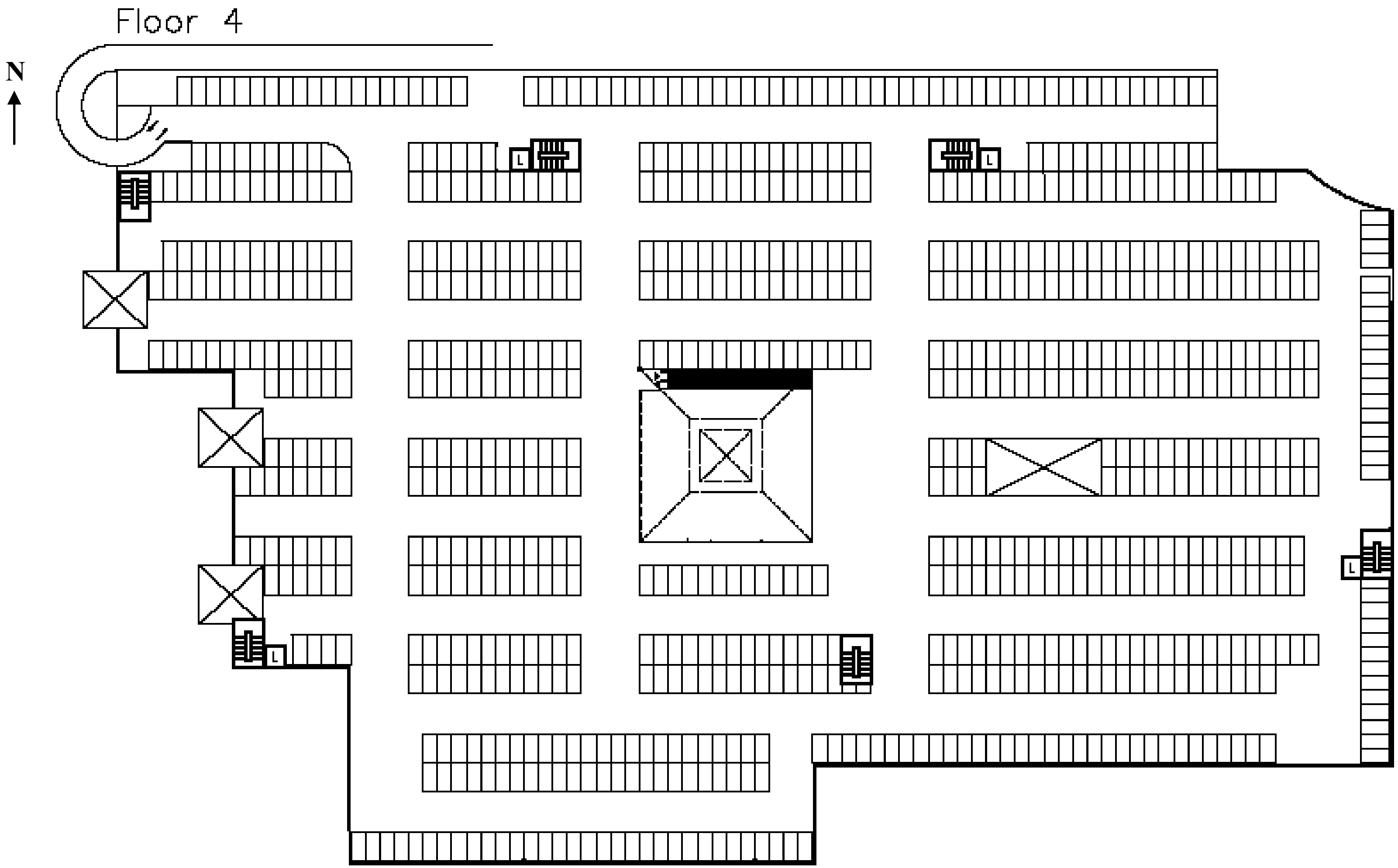


Figure 7.8: Designed Shopping Mall Building Plan – Floor 4

7.4 C/AS1 Design

7.4.1 Purpose Groups, Fire Hazard Category and Occupant Loads

The Purpose Group, Fire Hazard Category (FHC) and occupant loads for the shopping mall are summarised in Table 7.1. The building has total occupants of 11,648 occupants while majority of the occupants present on the retail floors. The area of retail floor includes pedestrian circulation areas to calculate the occupant load. Intermittent activities such as carparks, toilets, lifts and exitways are not assessed for occupant loads which have been included in other spaces.

Table 7.1: Purpose Group, FHC and occupant Load – Shopping Mall

	Location		PG	FHC	Occupant Density (persons/m^2)	Area (m^2)	Occupant load (persons)
Floor 1	Carpark		IA	1	-	16710	-
	Storage		WM	3	0.03	2010	60
	Stairs/lifts		IE	1	-	330	-
	Escalators		IA	1	-	280	-
						Floor Area (m^2)	19330
						Total occupant loads (Floor1)	**60**
Floor 2	Retail space	shops	CM	2	0.3	14339	4302
		circulations				3841	1152
	Restaurant		CL	2	-	320	200
	Food court		CS	2	-	100	50
	Atrium		CM	2	0.3	600	180
	Carpark		IA	1	-	2496	-
	Stairs/lifts		IE	1	-	330	-
	Escalators		IA	1	-	150	-
	Toilets		IA	1	-	450	-
						Floor Area (m^2)	22626
						Total occupant loads (Floor2)	**5884**
Floor 3	Retail space	shops	CM	2	0.3	14339	4302
		circulations				3841	1152
	Restaurant		CL	2	-	320	200
	Food court		CS	2	-	100	50
	Carpark		IA	1	-	2850	-
	Stairs/lifts		IE	1	-	330	-
	Escalators/Atrium void		IA	1	-	750	-
	Toilets		IA	1	-	450	-
						Floor Area (m^2)	22980
						Total occupant loads (Floor3)	**5704**
Floor 4	Carpark		IA	1	-	21699	-
	Stairs/lifts		IE	1	-	330	-
	Escalators(Atrium)		IA	1	-	750	-
						Floor Area (m^2)	22779
						Total occupant loads (Floor4)	**0**
						Total occupant loads of the building	**11648**

7.4.2 Requirements for Firecells

Under C/AS1, the building is divided into the following firecells to control fire spread as shown in Figure 7.9 and Figure 7.10 for the ground floor and retail floor. There is no fire separation required for the top floor / roof.

- Storage area and carpark on the ground floor shall be separate firecells respectively;
- Entrance to the escalators on the ground floor shall be fire separated from the carparking area;
- Carparks on Floor 2, 3, and 4 are contained in one firecell;
- Floor 2 & 3 are contained in one atrium firecell. It shall be noticed the atrium firecell (Floor 2 &3) does not meet the requirements of limited area atrium firecells in C/AS1, where the area of intermediate floor (Floor 3) is much greater than 500 m^2 and total occupants loads exceeds 500. Specific design is required for smoke control;
- As the occupant load on the retail floor exceeds 500, according to *Clause 6.4.1 C/AS1*, adjacent storage areas in which goods are received, unpacked, stored, packed for dispatch, or areas used for workshops, and display material storage etc. shall be smokecells separated from the display and sales areas;
- All staircases except for the escalators in the atrium, shall be enclosed as safe paths and provide egress directly to a safe place;
- All lifts and service shafts shall be enclosed within protected shafts.

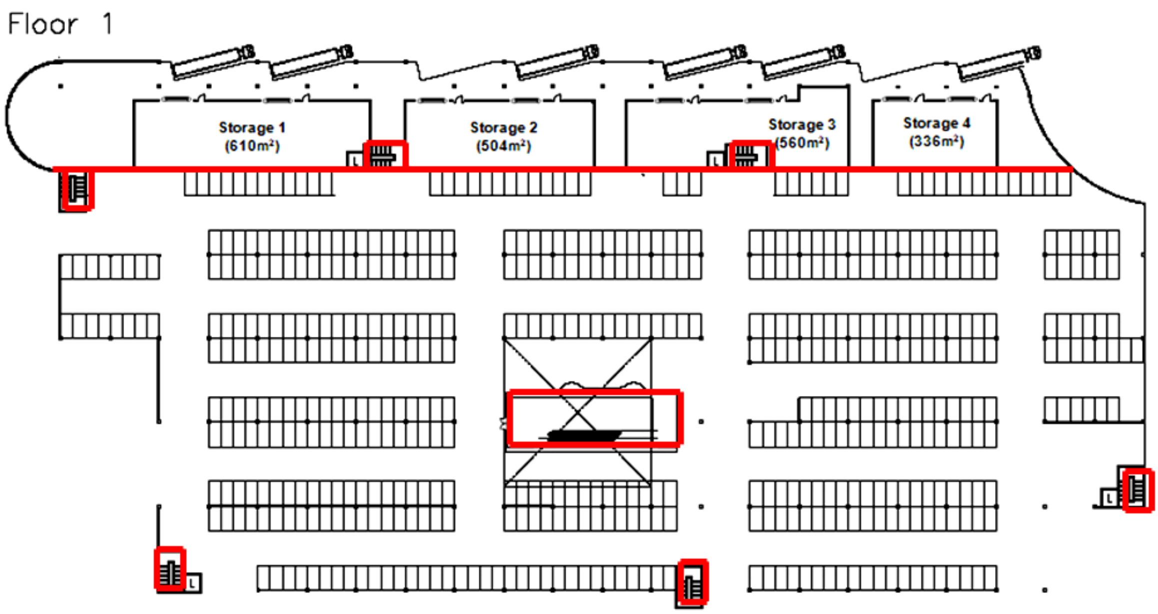


Figure 7.9: Firecell separation of the proposed shopping mall on Floor 1

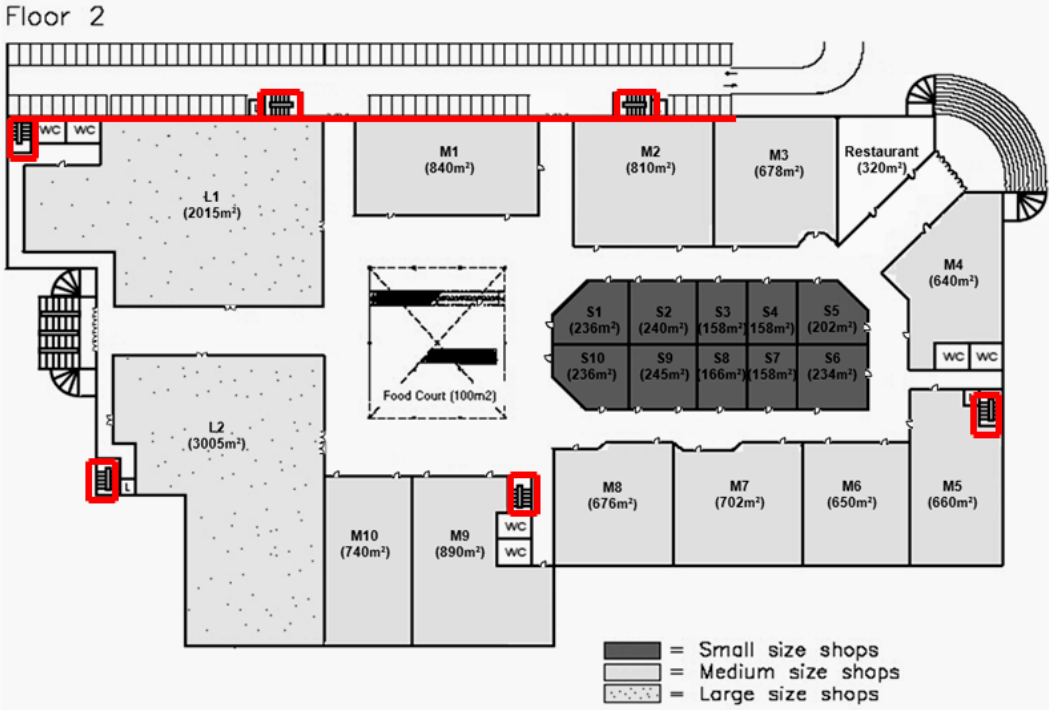


Figure 7.10: Firecell separation of the proposed shopping mall on Floor 2

For this building height and occupancy, the minimum firecell ratings, alarm types and fire safety systems are summarised in Table 7.2. As each carparking area has effective cross ventilation (satisfy *Clause 6.10.6 C/AS1*), no smoke control or other FSPs are required. According to *Clause 4.5.10 C/AS1*, storage and all carparking areas except for the roof shall have heat detectors with manual call points. Fire hydrant is not required in storage firecell as Fire Service Access is no greater than 75 m, but required in all other firecells where Fire Service Access exceeds 75 m.

It shall be noticed where fire separations are not required between retail area (purpose group CM) and restaurant (purpose group CL) on the same floor, the FSPs adopted for the whole floor shall be those of the primary purpose group, which is CM as it occupies over 40 % of the total firecell floor area. Even though, the ground floor firecells are permitted to have a F0 rating, it required to be fire separated from adjoining firecells with FRR no less than 30/30/30.

Table 7.2: Fire Safety Precautions in the shopping mall

Firecell Location		**Escape Height (m)**	**PG**	**F Rating (minutes)**	**Alarm Type**	**Other Protection Required**
Floor 1	Carpark	0	IA	0	HD, MCPs	Nill
	Storage	0	WM	0	HD, MCPs	Visibility in escape routes
Floor 2 & 3	Carpark		IA	0	HD, MCPs	Nill
	Retail	6.9	CM	30	SPK, SD, MCPs	▪ Smoke control ▪ Visibility in escape routes ▪ Fire hydramt system
Floor 4	Carpark	11.4	IA	0	Nill	Nill

Key: SPK – Sprinklers SD – Smoke detectors MCPs – Manual Call Points

According to Table 2.3, the area of carparking on ground floor exceeds 5000 m^2 and it shall be sprinklered if fire separation is undesirable. The area of the storage firecell exceeds 1500 m^2 and it shall be sprinklered if fire separation is undesirable. The area of Floor 2 & 3 can be unlimited as sprinkler system will be installed. Carparking on Floor 2 & 3 are 2496 m^2 and 2850 m^2 respectively, which are within the limitations. The roof carparking can have unlimited area.

7.4.3 Means of Escape

7.4.3.1 Number and Width of Escape Routes

As the building will be sprinklered, it is not required to provide extra width to allow for the possibility that one escape route may be unusable. The required number and width of escape routes are summarised in Table 7.3 for room origin and Table 7.4 for each floor. In reality, shops in the shopping mall normally have full height roller doors which remain open during the business hours to create an open view for customers. In this study, to minimize redundancy in the egress calculation and for the worst case condition in the shop of fire origin, the minimum required widths by C/AS1 were used in the tenability analysis.

Table 7.3: Width and Number of Escape Routes from room origin – Shopping mall

Location		Serving Occupancy (persons)	Number of Egress		Type of Travel	Width (mm)	
			Required	Available		Required	Available
Storage	1	18	1	2	H	850	1720
	2	15	1	2	H	850	1720
	3	17	1	2	H	850	1720
	4	10	1	2	H	850	1720
Large Shop	L1	605	3	3	H	4235	4300
	L2	901	3	3	H	6307	6880
Medium Shop	M1	252	2	3	H	1764	2580
	M2	243	2	2	H	1701	1720
	M3	203	2	2	H	1421	1720
	M4	192	2	2	H	1344	1720
	M5	198	2	2	H	1386	1720
	M6	195	2	2	H	1365	1720
	M7	211	2	2	H	1477	1720
	M8	203	2	2	H	1421	1720
	M9	267	2	2	H	1869	2580
	M10	222	2	2	H	1554	1720
Small Shop	S1	71	2	2	H	850	1720
	S2	72	2	2	H	850	1720
	S3	47	1	1	H	850	860

Location		Serving Occupancy (persons)	Number of Egress		Type of Travel	Width (mm)	
			Required	Available		Required	Available
	S4	47	1	1	H	850	860
	S5	61	2	2	H	850	1720
	S6	70	2	2	H	850	1720
	S7	47	1	1	H	850	860
	S8	50	1	1	H	850	860
	S9	74	2	2	H	850	1720
	S10	71	2	2	H	850	1720
Restaurant		200	2	2	H	1400	1720

Table 7.4: Width and Number of Escape Routes from floor level – Shopping mall

Location	Serving Occupancy (persons)	Number of Egress		Type of Travel	Width (mm)	
		Required	Available		Required	Available
Floor 1	374	2	>2	H	2618	>2618
Floor 2	5884	6	8	H	41188	41280
				V	52956	60000
Floor 3	5704	6	8	H	39928	41280
				V	51336	56000
Floor 4	434	2	6	H	3038	>3038
				V	3906	>3906

Floor 2 has total of eight exits, including two main entrances with door width of 10.32 m each, and six internal staircases with clear width of 3.5 m and door width of 3.44 m each. Spiral stairs, which are connected with the main entrance stairs, provide directly access to Floor 3 with clear width of 10 m each for the northeast entrance and 7.5 m each for the west entrance.

Based on *Clause 6.0 D1/AS1*, all stairways shall have at least one handrail and for accessible stairs, handrails are required on both sides. Handrails shall not project more than 100 mm into width. Stairways wider than 2000 mm shall be provided with intermediate handrails, equally spaced and providing a width not greater than 1500 mm for each section of the stairway. Curved or spiral stairs shall meet all requirements in *Clause 4.4 & Figure 17 D1/AS1*.

7.4.3.2 Length of Escape Routes

Given the purpose groups, the maximum escape route lengths are summarised in Table 7.5. For purpose group CM, CL, CS and IA, the allowable open path lengths are increased by 100 % for sprinklers, 100 % for smoke detectors and 20% for heat detectors. On entering the safe path stairs the occupants are considered to have ended their travel distance. The open path length on Floor 3 (considered as intermediate floor) does not required to be taken as 1.5 times the measured length as smoke control system will be installed.

Table 7.5: Length of Escape Route - Shopping mall

Location			PG	Dead End Open Path (m)		Total open Path (m)	
				Allowed	Actual	Allowed	Actual
Floor 1	Storage	1	WM	48	0	120	48
		2			0		41
		3			0		49
		4			0		38
	Carparking		IA	72	0	180	108
Floor 2 & 3	Large shop	L1	CM	54	0	135	90
		L2			0		120
	Medium shop	M1	CM	54	0	135	89
		M2			0		105
		M3			0		121
		M4			0		67
		M5			0		73
		M6			0		112
		M7			0		99.5
		M8			0		124.5
		M9			0		126
		M10			0		119
	Small shop	S1	CM	54	0	135	73
		S2			0		82
		S3			47		94
		S4			47		92
		S5			0		57
		S6			0		69
		S7			47		95
		S8			50		101
		S9			0		92
		S10			0		82
	Restaurant		CL	54	0	135	79.5
	Food court		CS	54	0	135	55
	Carparking		IA	43.2	0	108	65
Floor 4	Carparking		IA	-	0	no limit	93

7.4.3.3 External Escape

According to *Clause 3.14 C/AS1*, where an escape route enters a space exposed to the open air stairway or a balcony, it shall meet the requirements for a safe path between that point and the final exit. The escape route shall be either separated by distance from the external wall or providing alternative directions of escape. Where external spiral stairs on Floor 3 have only one direction of escape, external walls shall have no unprotected areas closer to an external escape route than 1.0 m if all firecells passed by the external escape route are sprinklered.

7.4.4 Internal and External Spread of Fire and Smoke

7.4.4.1 Fire Resistant Rating

According to *Clause 6.2.1 C/AS1*, carparking and storage firecells shall be fire separated from each other, and have a fire resistant rating of no less than 30/30/30. On Floor 2 & 3, retail firecell shall be fire separated from carparking area by FRR of 30/30/30. According to *Clause 6.10.5 C/AS1*, S rating shall be applied to building elements in car parking spaces as shown in Table 7.6.

Table 7.6: S Rating for carparking firecells

Variable	**Value**			
	Floor 1		**Floor 2 & 3**	
	Fire Separations	**Floors**	**Fire Separations**	**Floors**
A_v/A_f	<0.05	<0.05	>0.25	>0.25
A_h/A_f	0	0	0	0
FHC	1	1	1	1
t_e (from *Table 5.1 C/AS1*)	90	90	30	30
C	0.5	0.25	1	0.5
S Rating = $C \cdot t_e$ (minutes)	45	23	30	15

The safe path stairs shall have FRR of F30. The S rating required for the external walls is a function of the area of unprotected openings and the distance to the boundary. For 100 % unprotected openings, the retail firecell (FHC 2), sprinklered, requires a minimum distance to the boundary of 8.4 m; the carpark (FHC 1), unsprinklered, requires 10 m. The building has been designed assuming 2 street frontages with access for trucks on the three remaining sides that distance to the boundary is over 10 m, so no FRR is required to them that 100 % unprotected openings are permitted, except that no unprotected areas permitted closer to an external escape route than 1.0 m. According to *Clause 7.9.10 C/AS1*, there are no requirements for protecting the external walls against external vertical fire spread where firecells are sprinklered.

7.4.4.2 Surface Finishes

The exterior and interior surface finishes for this occupancy must meet the requirements of C/AS1 with respect to inhibiting the spread of fire. The interior surface finishes of the walls, ceilings, floor linings, and air ducts serving more than one firecell in purpose groups IE, CS, CL, and CM, shall have surface finishes satisfying the following requirements as shown below in Table 7.7.

Table 7.7: Requirements for Surface Finishes in the shopping mall

Building Elements	Purpose Group or Location	SFI	SDI	FI
Walls, Ceilings	Exit way	0	3	-
	All occupied spaces in purpose groups CS and CL	2	5	-
	All occupied spaces in purpose group CM where the occupant load is greater than 50			
	Passageways, corridors and stairways not being part of an exitway in all purpose groups except SH and SR	7	5	-
	Minimum requirement for all occupied spaces in all purpose groups except household units	5	10	-
Flooring (Coverings)	Exitways.	Non-combustible or have low radius of effects of ignition		
Ducts for HVAC systems	Internal surfaces	0	3	-
	External surfaces	7	5	-
Suspended flexible fabrics	All occupied spaces in CS and CL including exitways	-	-	12
	All occupied spaces including exitways in CM where occupant load greater than 50			
	Underlay to exterior cladding or roofing when exposed to view in occupied spaces in purpose groups SC,SA, WL, CM, CS, CL and IE.	-	-	5
Membrane structures	Purpose groups CM, CS and CL	-	-	12

Key: SFI = spread of flame index SDI = smoke developed index FI = flammability index

In firecells constructed without foamed plastics, and equipped with sprinklers, only the ceiling shall comply with the SFI and SDI requirements. Where foamed plastic building materials are used in wall, ceiling or roof systems, the foamed plastics materials shall meet the following requirements as shown in Table 7.8.

Table 7.8: Requirements for foamed plastics materials in the shopping mall

Application	Required Properties		
Exitways sprinklered	fb + p	fb + p	fb + p
Non-sleeping occupied spaces sprinklered	sf + p	fb + p	sf + p
Concealed spaces	p	fb + p	p

Key: p – foamed plastics shall comply with the flame propagation criteria as specified in AS 1366
fb – flame barrier complying with Appendix C C9.1 of C/AS1

7.4.4.3 Smoke Control in the Atrium

The atrium firecell (Floor 2 & 3) does not meet the requirements of limited area atrium firecells in C/AS1, where the area of intermediate floor (Floor 3) is much greater than 500 m^2 and total occupants loads exceed 500. According to comments in *Clause 6.21.4 C/AS1*, specific design is required to determine extract capacities of mechanical smoke extract for high occupant loads.

(1) Smoke Reservoir

As per *Clause 6.22.9 C/AS1*, a smoke reservoir shall be no greater than 1000 m^2 in plan area and have a maximum dimension of 60 m in any direction. The atrium space is 30 m long by 25 m wide with plan area of 750 m^2, which satisfy the requirements.

The design solutions (as per C/AS1) are based on an objective of maintaining a smoke layer at a height of at least 2.0 m above the highest intermediate floor open to the atrium space. That height shall be retained for 3.0 minutes for unvented smoke reservoir option, which takes into account the detection time, e.g. smoke detector activation, which activates the smoke exhaust system, and time that mechanical smoke extract system reaches its full exhaust capacity.

The required volume of smoke reservoir is calculated using the method by Karlsson & Quintiere (2000)[42] as shown in APPENDIX I. The smoke reservoir shall have a depth of 4.8 m. Smoke barriers are required over the atrium space, which shall extend to 2.7 m above the highest mezzanine floor (Floor 3).

(2) Mechanical Smoke Extract System

The extract capacity of the mechanical smoke extract system is calculated using the method by Klote & Milke (2000) [77] as shown in APPENDIX J. The ability of sprinklers to suppress fires where the ceilings are higher than 11 to 15 m is limited (Klote 2002), due to the entrainment of cold air into the plume lowering the temperature of the smoke layer. This delays or prevents the activation of the sprinkler. Therefore, the steady state fire size is taken as 20 MW according to the proposed C/VM2 for non-intervention fire. The smoke extract system is designed to maintain a smoke layer at a height of 2.7 m above Floor 3. The extract capacity is required to be 75 m^3/s with inlet area of 10.6 m^2. Only one extract point is required.

7.4.5 Fire Fighting

The building have track access on the north side and two street frontages on the three remaining sides, which provide Fire Service vehicular access within 18 m on each side of the building. Fire hydrant system will be installed throughout the building except for the storage firecell on the ground floor where Fire Service vehicular access does not exceed 75 m. Fire hydrant systems shall comply with *NZS 4510:2008 Fire Hydrant Systems for Buildings*[61]. According to *Clause 8.2.4 C/AS1*, in a building not required to have a fire systems center, the control features shall contain all control panels indicating the status of fire safety systems installed in the building, together with all control switches. Hand operated firefighting equipments, e.g. fire extinguishers, shall be provided and installed in compliance with *NZS 4503:2005 Hand Operated Fire-fighting Equipment*[59].

7.4.6 Summary of Design Features to Comply with C/AS1

The following design features are required to comply with C/AS1:

- Sprinkler system with smoke detectors and manual call points are required for all retail firecells. Sprinklers are installed on the ground floor to meet the firecell area requirements. Heat detectors with manual call points are required in carparking area on Floor 2 & 3. Detectors shall be interconnected;
- Retail firecells, internal staircases and storage firecell shall have a FRR of 30/30/30. S rating shall be applied to building elements in carparking spaces as shown in Table 7.6;
- All locking devices on doors on escape routes should be clearly visible, located where such a device would be normally expected, designed to be easily operated without a key or other security device, and allow the door to open in the normal manner;
- Doors on escape routes are required to open in the direction of escape if there are more than 20 occupants (or 10 occupants into exitways) using the doors;
- Doors within fire separation shall achieve a FRR same as required for the fire separation;
- Fire hydrant system is required throughout the building except for the storage firecell;
- Illuminated exit signs are required throughout the building in accordance with *F8/AS1*;
- Emergency lighting is required throughout the building in accordance with *F6/AS1*;
- Smoke barriers are required over the atrium space, which shall extend to 2.7 m above the highest mezzanine floor (Floor 3).
- Mechanical smoke extract system is required over atrium space, which shall have extract capacity of 75 m^3/s with inlet area of 10.6 m^2. One extract point is required;
- Interior surfaces shall meet all requirements as in Table 7.7 and Table 7.8.

7.5 C/VM2 Analysis

7.5.1 DFS 1 – Challenging Fire

Any room / space having area greater than 200 m^2 or with occupant load greater than 150 require analysis under Fire Scenario 1, including: Large shop, Medium shop, Small shop, Restaurant and Atrium space on the retail floor; Storage on the ground floor; and carparking areas. All other rooms are less than 200 m^2 and have less than 150 occupants. Carparking areas were not analysed which have large full wall opening at three sides. Storage on the ground floor was not analysed which have low occupancy with direct egress to outside. The other five locations were analysed using BRANZFIRE modelling to determine the Available Safe Egress Time (ASET).

Each retail floor has two large size shops, ten medium size shops and ten small size shops. Instead of analyzing all shop spaces, only those which require the longest egress time from room origins (refer to APPENDIX K) were modelled, including: Large shop L1, Medium shop M2 and Small shop S9.

An example input file in BRANZFIRE for fire in the Medium shop M2 on Floor 2 is attached in APPENDIX H-3. The building construction materials for interior walls, ceilings and floors are summarised in Table 7.9.

Table 7.9: Construction materials as modelled in BRANZFIRE – Shopping Mall

	Wall	**Ceiling**	**Floor**
Surface	100mm concrete	100mm concrete	100mm concrete
Substrate	-	-	-

7.5.1.1 ASET – BRANZFIRE Modelling

Figure 7.11 shows the geometry input in BRANZFIRE. Room 10 is modelled in turn for fire in shop and restaurant respectively. The geometry of rooms and details of vents used in BRANZFIRE modelling are given in Table 7.10 and Table 7.11. For the worst case condition in the room of fire origin, the widths of door vents in the analysis are the minimum required by C/AS1.

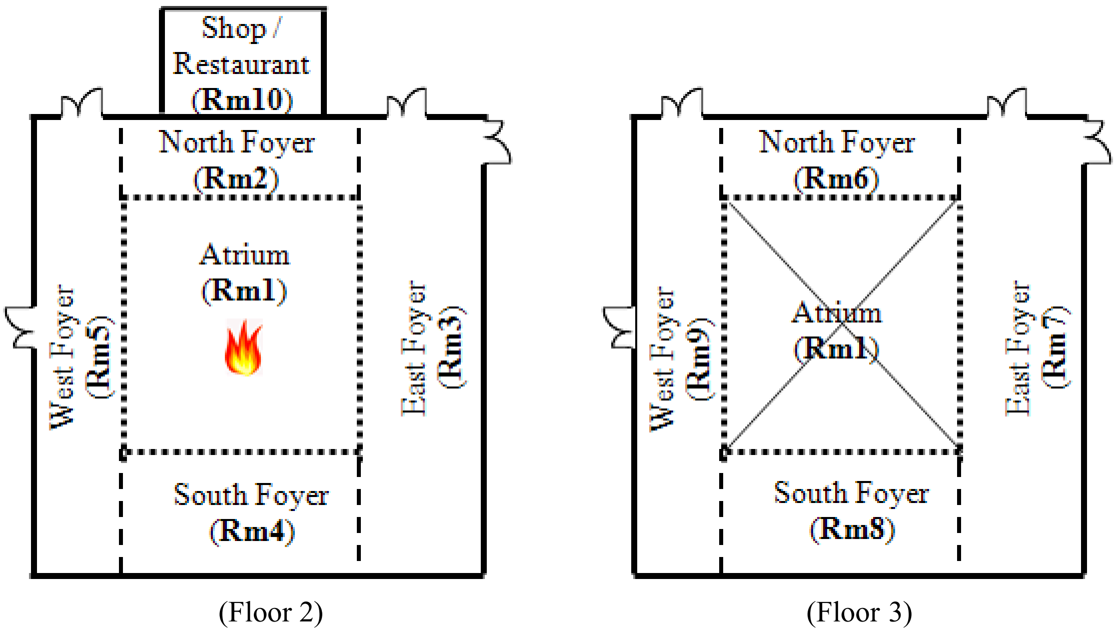


Figure 7.11: Geometry showing the rooms as modeled in BRANZFIRE – Shop/Restaurant fire on Floor 2

Table 7.10: Geometry of rooms as modeled in BRANZFIRE - Retail floors

Floor	Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height(m)
Floor 2	Atrium	1	30	25	12	0	2
	North foyer	2	25	11	4.5	0	2
	East foyer	3	53	25	4.5	0	2
	South foyer	4	25	12	4.5	0	2
	West foyer	5	53	36.6	4.5	0	2
Floor 3	North foyer	6	25	11	4.5	4.5	2
	East foyer	7	53	25	4.5	4.5	2
	South foyer	8	25	12	4.5	4.5	2
	West foyer	9	53	36.6	4.5	4.5	2
Floor 2	Large shop(L1)	10	67	30	4.5	0	2
	Medium shop(M2)		30	27	4.5	0	2
	Small shop(S9)		16	15.3	4.5	0	2
	Restaurant		25	12.8	4.5	0	2

Table 7.11: Geometry of vents as modeled in BRANZFIRE - shopping mall

Fire Location	Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)
	1 to 2	25	4.5	0	Open wall	Open	Always
	1 to 3	30	4.5	0	Open wall	Open	Always
	1 to 4	25	4.5	0	Open wall	Open	Always
	1 to 5	30	4.5	0	Open wall	Open	Always
	1 to 6	25	4.5	4.5	Open wall	Open	Always
	1 to 7	30	4.5	4.5	Open wall	Open	Always
	1 to 8	25	4.5	4.5	Open wall	Open	Always
	1 to 9	30	4.5	4.5	Open wall	Open	Always
	2 to 3	11	4.5	0	Open wall	Open	Always
	2 to 5	11	4.5	0	Open wall	Open	Always
	3 to 4	12	4.5	0	Open wall	Open	Always
	3 to outside	1.72	2	0	Fire door	Self-closing	146
		5.16	2	0	External door	Self-closing	146
	4 to 5	12	4.5	0	Open wall	Open	Always
	5 to outside	1.72	2	0	Fire door	Self-closing	146
		5.16	2	0	External door	Self-closing	146
	6 to 7	11	4.5	0	Open wall	Open	Always
	6 to 9	11	4.5	0	Open wall	Open	Always
	7 to 8	12	4.5	0	Open wall	Open	Always
	7 to outside	1.72	2	0	Fire door	Self-closing	145
		5.16	2	0	External door	Self-closing	145
	8 to 9	12	4.5	0	Open wall	Open	Always
	9 to outside	1.72	2	0	Fire door	Self-closing	145
		5.16	2	0	External door	Self-closing	145

Fire Location	Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection(s)
Large shop (L1)	2 to 10	4.3	2	0	Door	Open	Always
	10 to outside	0.031	4.5	0	Leakage	Open	Always
Medium shop(M2)	2 to 10	1.72	2	0	Door	Open	Always
	10 to outside	0.029	4.5	0	Leakage	Open	Always
Small shop(S9)	2 to 10	1.72	2	0	Door	Open	Always
Restaurant	2 to 10	1.72	2	0	Door	Open	Always
	10 to outside	0.017	4.5	0	Leakage	Open	Always

7.5.1.2 ASET Results

The BRANZFIRE results for fire in Large shop (L1), Medium shop (M2), Small shop (S9), Restaurant, Atrium are summarised in Table 7.12. As the building is sprinklered, only FED CO applies for occupant tenability. All safe path staircases remain tenable condition during the simulation time of 1800 s.

Table 7.12: Summary of BRANZFIRE modelling results – Shopping mall

Fire Location		Space	Detection Time (s)	Time Reached (s)			ASET (s)
				FED CO = 0.3	FED Thermal = 0.3	Visibility = 10 m	
Large shop fire (L1)		fire origin(L1)	63 (SD)	>1800	1074	622	>1800
	F2	foyer		>1800	>1800	>1800	>1800
	F3	foyer		>1800	>1800	>1800	>1800
	internal staircases			>1800	>1800	>1800	>1800
Medium shop fire (M2)		fire origin(M2)	62 (SD)	1322	487	313	1322
	F2	foyer		>1800	>1800	>1800	>1800
	F3	foyer		>1800	>1800	>1800	>1800
	internal staircases			>1800	>1800	>1800	>1800
Small shop fire (S9)		fire origin(S9)	64 (SD)	800	258	160	800
	F2	foyer		>1800	>1800	>1800	>1800
	F3	foyer		>1800	>1800	>1800	>1800
	internal staircases			1800	>1800	>1800	>1800
Restaurant fire		fire origin (Restaurant)	64 (SD)	905	290	182	905
	F2	foyer		>1800	>1800	>1800	>1800
	F3	foyer		>1800	>1800	>1800	>1800
	internal staircases			1800	>1800	>1800	>1800
Atrium fire		Fire origin (Atrium)	103 (SD)	>1800	933	1665	>1800
	F2	foyer		>1800	>1800	>1800	>1800
	F3	foyer		>1800	>1800	>1800	>1800
	internal staircases			>1800	>1800	>1800	>1800

Key: SD – Smoke detectors

7.5.1.3 RSET Results

All occupants in the building are considered to be awake at the time of the fire and, as it is a public building, it is assumed occupants on retail floors are unfamiliar with the building layout and possible escape routes. Staff in storage firecell are considered familiar with escape routes. Occupants in carparking areas are considered intermittent and have been included in the retail firecells for egress calculations. Full details of egress calculations are provided in APPENDIX K.

(1) Large Shop L1 Fire

Results show that all occupants have been cleared from the fire origin at 197 s after alarm sounds. Safe path stairs reach full capacity at 212 s and the number of occupants into stairs is controlled by the stair discharging flow afterwards. The fire floor (Floor 2) is cleared at 266 s after alarm sounds and Floor 3 is cleared at 265 s. All occupants are cleared from stairs at 417 s and entire building is cleared at 485 s after alarm sounds. The results are summarised in Table 7.13.

Table 7.13: RSET results – Large shop fire

Events	Time (s)
Time to detection: t_d	63s (Smoke detection) 229s (Sprinkler activation)
Time for pre-movement: t_p	60s for occupants in Large shop L1 (fire origin) 120s for occupants in other spaces
Time for travel / flow : t_t	137s clear Large shop L1 (fire origin) into foyer
RSET for clear fire origin	= $t_d + t_p + t_t$ =63s+60s+137s=260s
RSET for clear floor of fire origin (Floor 2)	= $t_d + t_p + t_t$ =63s+120s+146s=329s
RSET for clear mezzanine floor (Floor 3)	= $t_d + t_p + t_t$ =63s+120s+145s=328s
RSET for clear entire building	= $t_d + t_p + t_t$ =63s+120s+365s=548s

(2) Medium Shop M2 Fire

Results show that all occupants have been cleared from the fire origin at 227 s after alarm sounds, which is governed by queuing. Safe path stairs reach full capacity at 212 s and the number of occupants into stairs is controlled by the stair discharging flow afterwards. The fire floor (Floor 2) is cleared at 265 s after alarm sounds and Floor 3 is cleared at 269 s. All occupants are cleared from stairs at 420 s and entire building is cleared at 488 s after alarm sounds. The results are summarised in Table 7.14.

Table 7.14: RSET results – Medium shop fire

Events	Time (s)
Time to detection: t_d	62s (Smoke detection) 209s (Sprinkler activation)
Time for pre-movement: t_p	60s for occupants in Medium shop M2 (fire origin) 120s for occupants in other spaces
Time for travel / flow : t_t	167s clear Medium shop M2 (fire origin) into foyer
RSET for clear fire origin	= $t_d + t_p + t_t$ =62s+60s+167s=289s
RSET for clear floor of fire origin (Floor 2)	= $t_d + t_p + t_t$ =62s+120s+149s=331s
RSET for clear mezzanine floor (Floor 3)	= $t_d + t_p + t_t$ =62s+120s+145s=327s
RSET for clear entire building	= $t_d + t_p + t_t$ =62s+120s+368s=550s

(3) Small Shop S9 Fire

All occupants have been cleared from the fire origin at 111 s after alarm sounds, which is governed by queuing. Safe path stairs reach full capacity at 211 s and the number of occupants into stairs is controlled by the stair discharging flow afterwards. The fire floor (Floor 2) is cleared at 269 s after alarm sounds and Floor 3 is cleared at 265 s. All occupants are cleared from stairs at 421 s and the entire building is cleared at 489 s after alarm sounds. The results are summarised in Table 7.15.

Table 7.15: RSET results – Small shop fire

Events	Time (s)
Time to detection: t_d	64s (Smoke detection) 187s (Sprinkler activation)
Time for pre-movement: t_p	60s for occupants in Small shop S9 (fire origin) 120s for occupants in other spaces
Time for travel / flow : t_t	51s clear Small shop S9 (fire origin) into foyer
RSET for clear fire origin	= $t_d + t_p + t_t$ =64s+60s+51s=175s
RSET for clear floor of fire origin (Floor 2)	= $t_d + t_p + t_t$ =64s+120s+149s=333s
RSET for clear mezzanine floor (Floor 3)	= $t_d + t_p + t_t$ =64s+120s+145s=329s
RSET for clear entire building	= $t_d + t_p + t_t$ =64s+120s+369s=553s

(4) Restaurant Fire

All occupants have been cleared from the fire origin at 198 s after alarm sounds, which is governed by queuing. Safe path stairs reach full capacity at 212 s and the number of occupants into stairs is controlled by the stair discharging flow afterwards. The fire floor (Floor 2) is cleared at 268 s after alarm sounds and Floor 3 is cleared at 265 s. All occupants are cleared from stairs at 420 s and entire building is cleared at 488 s after alarm sounds. The results are summarised in Table 7.16.

Table 7.16: RSET results – Restaurant fire

Events	Time (s)
Time to detection: t_d	64s (Smoke detection) 193s (Sprinkler activation)
Time for pre-movement: t_p	60s for occupants in the Restaurant (fire origin) 120s for occupants in other spaces
Time for travel / flow : t_t	137s clear Restaurant (fire origin) into foyer
RSET for clear fire origin	= $t_d + t_p + t_t$ =64s+60s+137s=261s
RSET for clear floor of fire origin (Floor 2)	= $t_d + t_p + t_t$ =64s+120s+148s=332s
RSET for clear mezzanine floor (Floor 3)	= $t_d + t_p + t_t$ =64s+120s+145s=329s
RSET for clear entire building	= $t_d + t_p + t_t$ =64s+120s+368s=552s

(5) Atrium Fire

Fire is located in the atrium area on Floor 2. Occupants in the atrium and foyer (pedestrian circulation area) are considered aware of the fire sooner than occupants in other spaces remote from the fire and have a pre-movement time of 60 s. Occupants in other spaces on the retail floors have pre-movement times of 120 s. The fire floor (Floor 2) is cleared at 227 s after alarm sounds and Floor 3 is cleared at 257 s. All occupants are cleared from stairs at 408 s and entire building is cleared at 476 s after alarm sounds. The results are summarised in Table 7.17.

Table 7.17: RSET results – Atrium fire

Events	Time (s)
Time to detection: t_d	103s (Smoke detection) 513s (Sprinkler activation)
Time for pre-movement: t_p	60s for occupants in atrium & foyeron Floor 2 120s for occupants in other spaces
Time for travel / flow : t_t	167s clear Floor 2 (floor of fire origin)
ASET for clear floor of fire origin (Floor 2)	= $t_d + t_p + t_t$ =103s+120s+107s=330s
ASET for clear mezzanine floor (Floor 3)	= $t_d + t_p + t_t$ =103s+120s+137s=360s
ASET for clear entire building	= $t_d + t_p + t_t$ =103s+120s+356s=579s

7.5.1.4 RSET vs. ASET

As the building is sprinkler protected, only FED CO applies for occupant tenability. The visibility and FED for thermal effects are also included for reference. Once occupants leave the firecell of fire origin, they are considered temporarily safe. The results for RSET versus ASET and the safety margin are summarised in Table 7.18 to Table 7.22 for each fire location. The design will fail where RSET exceeds ASET. The results show the design meets the C/VM2 criteria at each fire locations.

Table 7.18: RSET vs. ASET results for large shop fire – Shopping mall

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Room of fire origin (Large shop L1 tenability)			
RSET(Large shop L1)		260	-
ASET	Visibility = 10 m	622	362 (N/A)
	FED Thermal = 0.3	1074	814 (N/A)
	FED CO = 0.3	>1800	>1540
Firecell of Fire Origin – Floor 2 (foyer tenability)			
RSET(Floor2)		329	-
ASET	Visibility= 10 m	>1800	>1471 (N/A)
	FED Thermal = 0.3	>1800	>1471 (N/A)
	FED CO = 0.3	>1800	>1471
Firecell of Fire Origin – Floor 3 (foyer tenability)			
RSET(Floor3)		328	-
ASET	Visibility = 10 m	>1800	>1472 (N/A)
	FED Thermal = 0.3	>1800	>1472 (N/A)
	FED CO = 0.3	>1800	>1472

N/A – Not applicable

Table 7.19: RSET vs. ASET results for medium shop fire – Shopping mall

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Medium Shop M2 (fire origin tenability)			
RSET(Medium shop M2)		289	-
ASET	Visibility = 10 m	313	24 (N/A)
	FED Thermal = 0.3	487	198 (N/A)
	FED CO = 0.3	1322	1033
Firecell of Fire Origin – Floor 2 (foyer tenability)			
RSET(Floor2)		331	-
ASET	Visibility= 10 m	>1800	>1469 (N/A)
	FED Thermal = 0.3	>1800	>1469 (N/A)
	FED CO = 0.3	>1800	>1469
Firecell of Fire Origin – Floor 3 (foyer tenability)			
RSET(Floor3)		327	-
ASET	Visibility = 10 m	>1800	>1473 (N/A)
	FED Thermal = 0.3	>1800	>1473 (N/A)
	FED CO = 0.3	>1800	>1473

N/A – Not applicable

Table 7.20: RSET vs. ASET results for small shop fire – Shopping mall

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Small Shop S9 (fire origin tenability)			
RSET(Small shop S9)		175	-
ASET	Visibility = 10 m	160	***-15*** (N/A)
	FED Thermal = 0.3	258	83 (N/A)
	FED CO = 0.3	800	625
Firecell of Fire Origin – Floor 2 (foyer tenability)			
RSET(Floor2)		333	-
ASET	Visibility= 10 m	>1800	>1467 (N/A)
	FED Thermal = 0.3	>1800	>1467 (N/A)
	FED CO = 0.3	>1800	>1467
Firecell of Fire Origin – Floor 3 (foyer tenability)			
RSET(Floor3)		329	-
ASET	Visibility = 10 m	>1800	>1471 (N/A)
	FED Thermal = 0.3	>1800	>1471 (N/A)
	FED CO = 0.3	>1800	>1471

*Values shown in **bold italic** show that RSET exceeds the ASET* *N/A – Not applicable*

Table 7.21: RSET vs. ASET results for restaurant fire – Shopping mall

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Restaurant (fire origin tenability)			
RSET(Restaurant)		261	-
ASET	Visibility = 10 m	182	***-79*** (N/A)
	FED Thermal = 0.3	290	29 (N/A)
	FED CO = 0.3	905	644
Firecell of Fire Origin – Floor 2 (foyer tenability)			
RSET(Floor2)		332	-
ASET	Visibility= 10 m	>1800	>1468 (N/A)
	FED Thermal = 0.3	>1800	>1468 (N/A)
	FED CO = 0.3	>1800	>1468
Firecell of Fire Origin – Floor 3 (foyer tenability)			
RSET(Floor3)		329	-
ASET	Visibility = 10 m	>1800	>1471 (N/A)
	FED Thermal = 0.3	>1800	>1471 (N/A)
	FED CO = 0.3	>1800	>1471

*Values shown in **bold italic** show that RSET exceeds the ASET* *N/A – Not applicable*

Table 7.22: RSET vs. ASET results for Atrium fire – Shopping mall

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Firecell of Fire Origin – Floor 2 (foyer tenability)			
RSET(Floor2)		330	-
ASET	Visibility= 10 m	1464	1134 (N/A)
ASET	FED Thermal = 0.3	1651	1321 (N/A)
ASET	FED CO = 0.3	>1800	>1470
Firecell of Fire Origin – Floor 3 (foyer tenability)			
RSET(Floor3)		360	-
ASET	Visibility = 10 m	832	472 (N/A)
ASET	FED Thermal = 0.3	>1800	1349 (N/A)
ASET	FED CO = 0.3	>1800	>1440

N/A – Not applicable

7.5.2 DFS 2 – Blocked Exit

According to the C/AS1 design, except that some small shops with occupant loads up to 50 have single escape routes from room origin, all other spaces have at least two means of escape equally sized. Therefore with one blocked exit in each space still have at least 50 % of the required exit width available. Each floor level has more than two vertical safe paths serving more than 250 occupants. Therefore this scenario is achieved.

7.5.3 DFS 3 – Fire in Unoccupied Room

The shopping mall contains unoccupied rooms, including storage areas adjacent to retail shops, lift machine rooms and cleaning rooms etc. The fire safety precautions for this building include a fully analogue addressable detection system installed throughout the building which satisfies this scenario.

7.5.4 DFS 4 – Fire in Concealed Space

The shopping mall building contains concealed space, including service shafts, curtain wall cavities, ceiling plenums etc. The fire safety precautions for this building include a fully analogue addressable detection system and a fully compliant sprinkler system installed throughout the building which satisfies this scenario.

7.5.5 DFS 5 – Smouldering Fire

This scenario addresses the fire safety concern regarding a slow, smouldering fire that causes a threat to sleeping occupants. There is no requirement to test this scenario in the shopping mall building where no sleeping occupants present. Therefore, this scenario is achieved.

7.5.6 DFS 6 – Fire Spread to Other Property

The performance objective of this scenario is to prevent fire spread to neighboring buildings as a result of radiative heat transfer. The acceptable methodologies include C/AS1 tabulated data for boundary distances. The building complies with the requirements of Part 7 of C/AS1. This scenario is achieved.

7.5.7 DFS 7 – Vertical External Fire Spread

The building does not have sleeping occupants on upper floors but with escape height over 10 m and this scenario applies. The exterior claddings of external walls are pre-cast concrete which have a peak heat release rate less than 100 kW/m^2 and satisfies Performance Measure 1. The building is sprinkler protected and satisfies Performance Measure 2. Therefore, this scenario is achieved.

7.5.8 DFS 8 – Interior Surface Finishes

This scenario applies to all buildings except that a smoke production rate criterion is not required for sprinkler protected buildings. The surface finishes of walls and ceilings in the safe path staircases will be plasterboard (Group 1 materials), achieving a time to flashover not less than 20 minutes. It satisfies Performance Measure 1. Walls and ceilings in other spaces will be plasterboard or fire retardant treated timbers (Group 1 or 2 materials), achieving a time to flashover not less than 10 minutes. It satisfies Performance Measure 3. Floor surfaces in safe paths will be concrete which is non-combustible. Smoke production rate criterion does not apply as the building is sprinkler protected. This scenario is achieved.

7.5.9 DFS 9 – Fire Service Operations

The objective of this scenario is to make a risk-informed judgement about how to tackle firefighting and rescue operations. Analysis for firefighter tenability is required for FHC 4 buildings over 1500 m^2 or unsprinklered buildings where the distance from the safe path access to any point on a floor exceeds 75 m. Therefore, firefighting tenability analysis is not required as the building is fully sprinklered.

To facilitate rapid size-up of the situation for firefighting, control panels indicating the status of fire safety systems will be installed in the building complied with *C/AS1 Part 8*. To facilitate safe access for rescue and firefighting, there is no point on a floor that is further than 75 m from a safe path access for firefighters. Structural stability criteria for firefighters are achieved by providing fire resistance ratings that comply with C/AS1. To facilitate adequate firefighting water, based on the C/AS1 design, internal hydrant system will be provided on all floors and the building is fully sprinkler protected.

7.5.10 DFS 10 – Robustness Check

The objective of this scenario is to do a robustness check with each key fire safety system rendered in effective in turn, including smoke management systems, and fire and/or smoke doors. Fire sprinklers and automatic fire alarms complied with New Zealand Standard are considered to be sufficiently reliable.

7.5.10.1 Smoke Control System

As the building has smoke control system over atrium space and failure of the smoke exhauster may expose over 150 occupants to untenable conditions, detailed tenability analysis is required under DFS 10. Based on the BRANZFIRE analysis in DFS 1, smoker layer drops much quicker when fire is located in the atrium than fire in other spaces. Therefore, the analysis was only carried out for fire in the atrium without smoke exhaust system. The results are summarised in Table 7.23. The design still meets the performance criteria without smoke control system over Atrium space.

Table 7.23: Results of tenability criteria – Atrium fire without smoke exhaust system

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Firecell of Fire Origin – Floor 2 (foyer tenability)			
RSET(Floor2)		330	-
ASET	Visibility = 10 m	762	432 (N/A)
	FED Thermal = 0.3	1401	1071 (N/A)
	FED CO = 0.3	>1800	>1470
Firecell of Fire Origin – Floor 3 (foyer tenability)			
RSET(Floor3)		360	-
ASET	Visibility = 10 m	329	***-31*** (N/A)
	FED Thermal = 0.3	1014	654 (N/A)
	FED CO = 0.3	>1800	>1440

N/A – Not applicable

7.5.10.2 Fire/Smoke Doors

Based on the BRANZFIRE analysis for DFS 1, the FED CO in the foyers on both retail floors never exceeds 0.3 during the simulation time of 1800 s for each fire location. It is rarely that all fire doors fail to remain their function at the same time. With one fire door into an internal staircase rendered ineffective, as the smoke filling into the staircase is much slower than that in the foyer, the staircase shall remain tenable for at least 1800 s while all occupants have cleared from the building. Therefore, the design still meets the performance criteria with one fire door is ineffective in functions.

7.6 Summary of Safety Margin for DFS 1

This section provides a summary of the safety margin that the C/AS1 compliant shopping mall can achieve under the C/VM2 principles for DFS 1. Fire protection systems in the shopping mall include a fully compliant sprinkler system and smoke detectors on both retail floors. Only FED CO is provided here in provision of sprinklers. As shown in Figure 7.12 and Figure 7.13, the design meets the current C/VM2 with safety factor of 3.5. The most critical fire location is in the restaurant. All safe path staircases and foyer spaces remain tenable condition during the entire simulation of 1800 s.

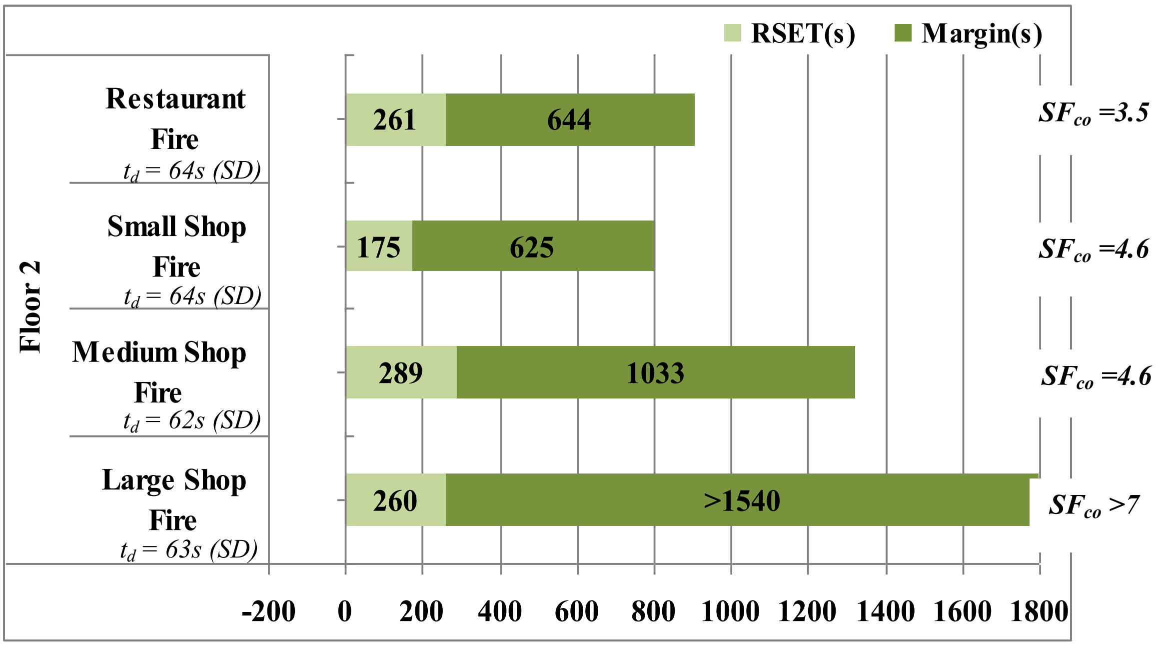


Figure 7.12: Shopping mall safety margin for room of fire origin

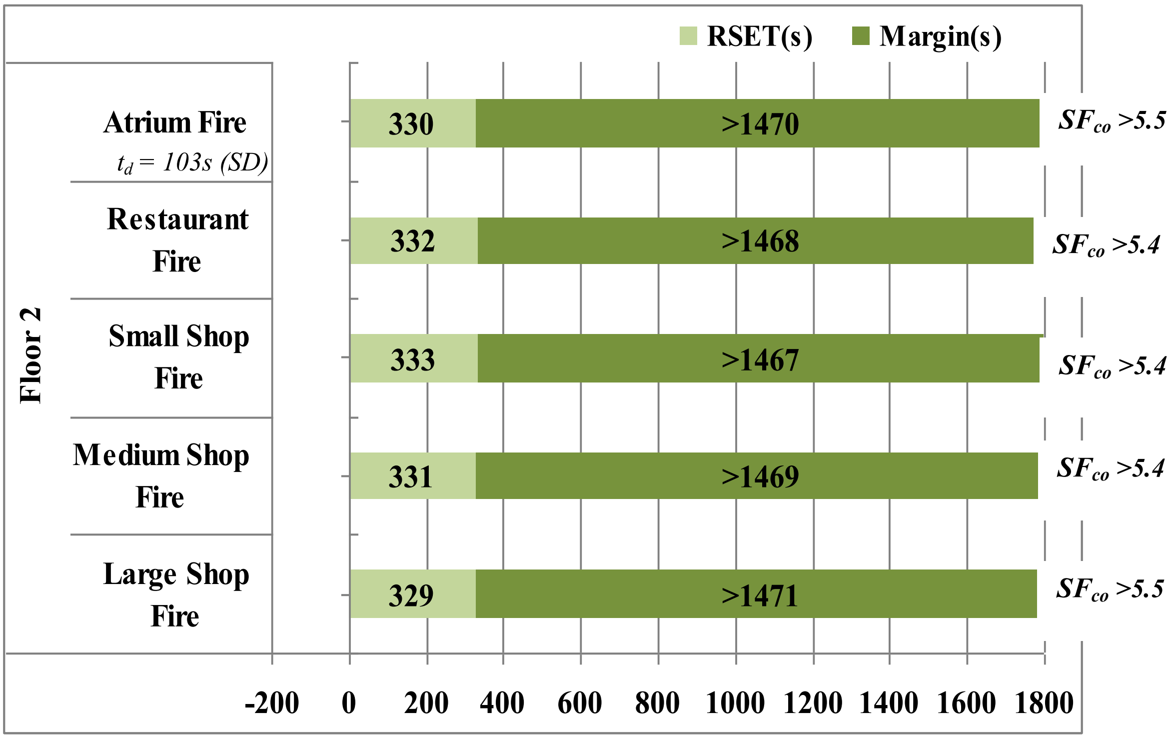


Figure 7.13: Shopping mall safety margin for firecell of fire origin (tenability in foyer)

7.7 Discussion

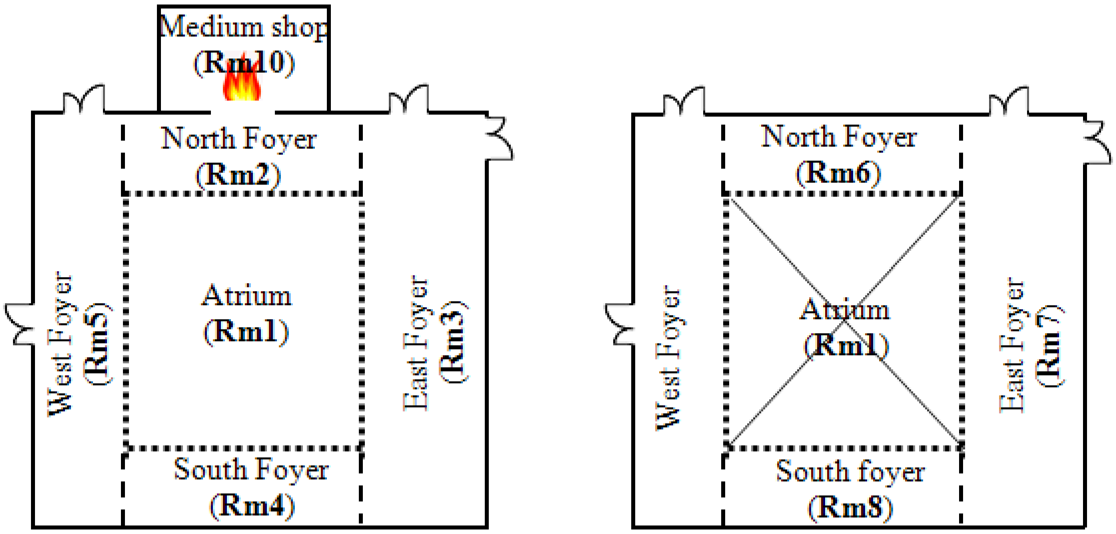
Even though there has been no large-scale loss of life in shopping mall fires[72], the potential for a fire disaster should not be dismissed considering its complex architecture, activity and crowded occupancy. In the event of fire, everyone in a mall must evacuate the premise as quickly and orderly as possible through use of multiple exits. Under the prescriptive solution, *Table 3.1 C/AS1* provides the minimum required number of escape routes from a floor level. The shopping mall, with over 5000 occupants on each floor, requires at least 6 egress routes in accordance with C/AS1. While the current C/VM2 only requires two exits which is governed by DFS 2: Blocked Exit.

In many design procedures, safety factors are applied to reduce the hazard to an acceptable level. If a fire may put a large number of people at risk, or in buildings where large numbers of occupants may be unfamiliar with all of the available exit routes, it is considered appropriate to include additional safety factors within the design[78]. As discussed in Section 5.6, it is considered that the proposed C/VM2 over benefits buildings with sprinkler system that a safety factor greater than 1.0 (e.g. 2.0) shall be achieved for FED CO where the building is sprinklered. It is also suggested that where a firecell containing more than 5000 occupants, a safety factor of 2.0 shall be achieved for FED CO and robustness check is required with sprinkler system rendered ineffective. Further analysis has been carried out in the following section in accordance to the above suggestions.

7.8 Sensitivity of System Failure

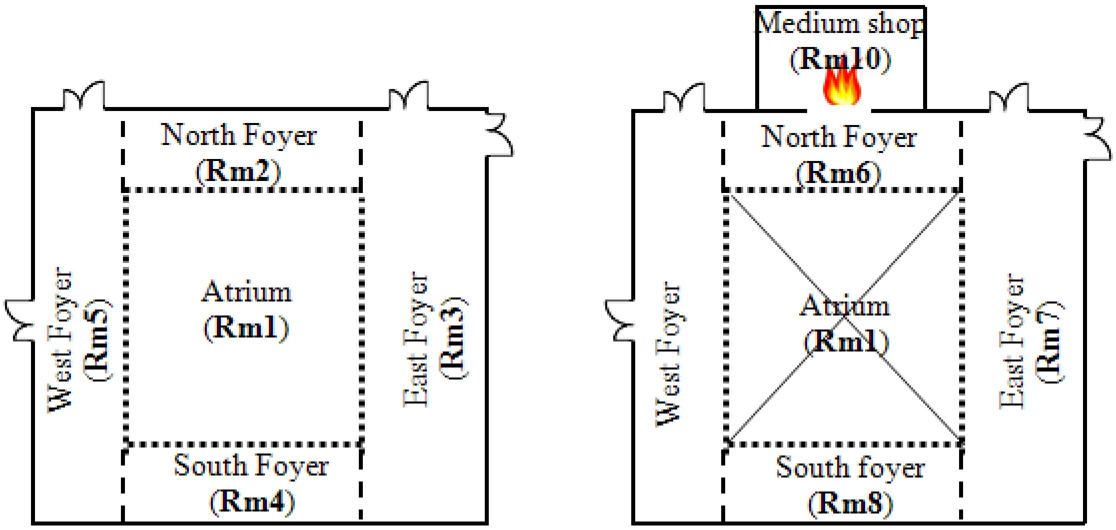
Based on the above suggestions, further analysis was carried out for failure of sprinkler system and an increased safety factor of 2.0 to be achieved. The fire was located in the medium shop M2 on either Floor 2 or Floor 3. Smoke control system may not be required in the atrium space for a performance-based design according to the results for DFS 10, hence not provided in this analysis. To maximize smoke spread from the shop into communicating space, the entire shop front is modelled as open which is assumed to have total width of 15 m taken as half of the wall width. As per C/VM2, only FED CO is applicable for tenability criteria.

The geometry in BRANZFIRE for a medium shop fire on Floor 2 and Floor 3 in turn is shown in Figure 7.14 and Figure 7.15 respectively. Details of rooms and vents are same as previous analysis except that shop front is modelled as fully open.



(Floor 2) (Floor 3)

Figure 7.14: Geometry as modeled in BRANZFIRE – Medium shop fire on Floor 2



(Floor 2) (Floor 3)

Figure 7.15: Geometry as modeled in BRANZFIRE – Medium shop fire on Floor 3

The RSET versus ASET results are summarised in Table 7.24. For fire in the Medium shop (M2) on Floor 2, FED CO reaches 0.3 after 1630 s on Floor 2 and 1954 s on Floor 3 with safety factor of 4.9 and 6.0 respectively. For fire in the Medium shop (M2) on Floor 3, FED CO on Floor 3 reaches 0.3 after 1037 s with safety factor of 3.2.

Table 7.25 summarises the minimum required egress width to achieve a safety factor of 2.0 compared to egress width required by C/AS1. Floor 2 requires total egress width of 12.9 m for a performance-based design to meet the suggested criteria, while C/AS1 requires a total clear width of 53 m. Floor 3 requires 12.9 m compared to 51.3 m required by C/AS1.

Table 7.24: RSET vs. ASET results for failure of sprinkler system

<table>
<tr><th></th><th colspan="2">Criteria</th><th>Time Reached (s)</th><th>Margin = ASET - RSET (s)</th></tr>
<tr><td rowspan="8">Floor 2 M2 Fire</td><td colspan="2">RSET to clear Floor 2</td><td colspan="2">331</td></tr>
<tr><td rowspan="3">ASET on Floor 2</td><td>Visibility= 10 m</td><td>632</td><td>301 (N/A)</td></tr>
<tr><td>FED Thermal = 0.3</td><td>>1800</td><td>>1469 (N/A)</td></tr>
<tr><td>FED CO = 0.3</td><td>1630</td><td>1299 (SF = 4.9)</td></tr>
<tr><td colspan="2">RSET to clear Floor 3</td><td colspan="2">327</td></tr>
<tr><td rowspan="3">ASET on Floor 3</td><td>Visibility = 10 m</td><td>569</td><td>242 (N/A)</td></tr>
<tr><td>FED Thermal = 0.3</td><td>>1800</td><td>>1473 (N/A)</td></tr>
<tr><td>FED CO = 0.3</td><td>1954</td><td>1627 (SF = 6.0)</td></tr>
<tr><td rowspan="4">Floor 3 M2 Fire</td><td colspan="2">RSET to clear Floor 3</td><td colspan="2">327</td></tr>
<tr><td rowspan="3">ASET on Floor 3</td><td>Visibility = 10 m</td><td>440</td><td>113 (N/A)</td></tr>
<tr><td>FED Thermal = 0.3</td><td>1217</td><td>890 (N/A)</td></tr>
<tr><td>FED CO = 0.3</td><td>1037</td><td>710 (SF = 3.2)</td></tr>
</table>

Table 7.25: Minimum required egress width to achieve safety factor of 2.0

Fire Location	Floor Level	Total egress width (m) required by C/VM2 to achieve SF of 2.0	Total egress width (m) required by C/AS1
Floor 2 M2 fire	Floor 2	12.9	53
	Floor 3	7.5	51.3
Floor 3 M2 fire	Floor 2	-	53
	Floor 3	11.5	51.3

7.9 FDS vs. BRANZFIRE

The graphic layout of the shopping mall in Smokeview is shown in Figure 7.16. In this case, fire was located at the geometric centre of the atrium area on Floor 2. In order to simulate a severe fire and resolve smoke movement through the building, neither smoke control nor sprinkler was provided in the modelling. The peak HRR was taken as 20 MW. A grid size of 200 mm was used in the atrium space where the fire originates whilst 400mm grid size was used elsewhere.

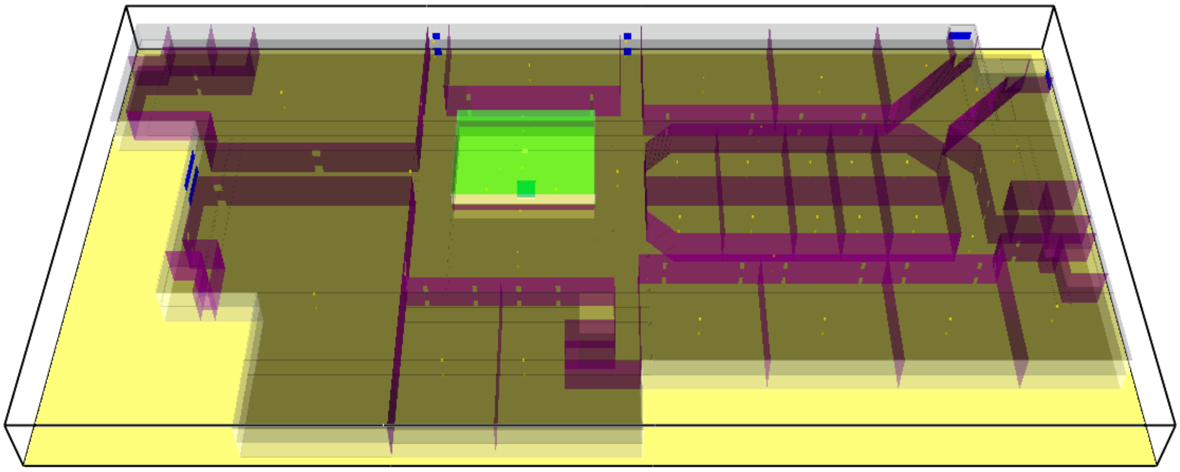
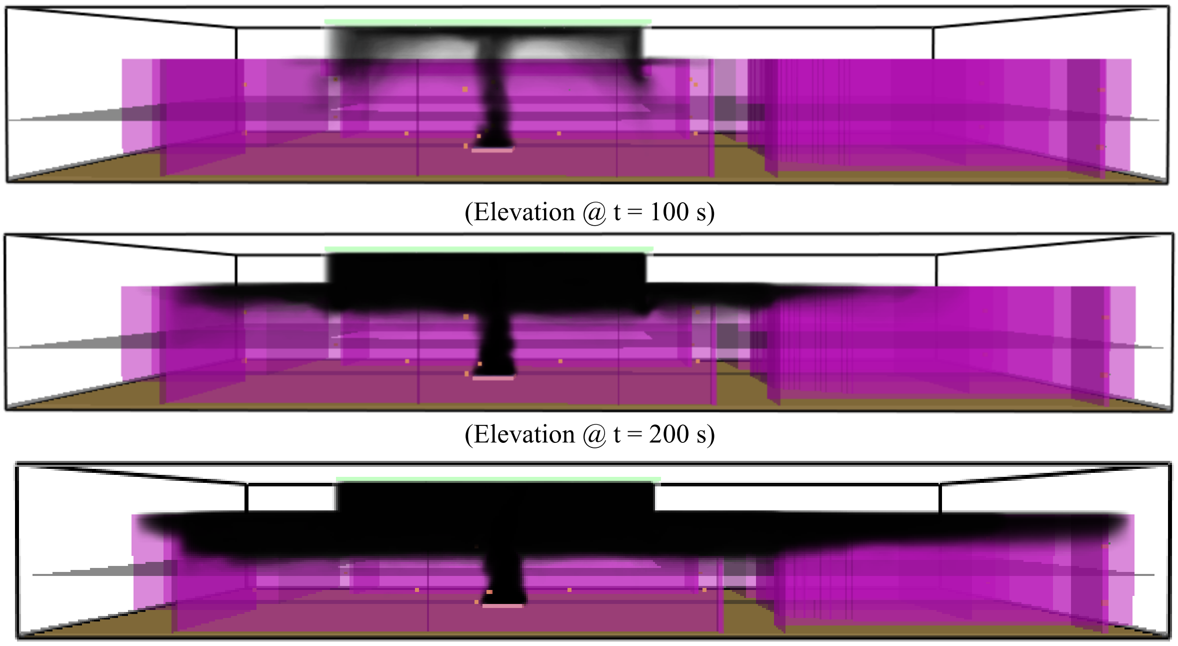


Figure 7.16: Shopping mall layout in Smokeview

Figure 7.17 shows the smoke movement from fire in the atrium spilling into the ceiling reservoir as well as foyer space on Floor 3. The smoke layer keeps dropping down that the results show visibility drops below 10 m after 329 s on Floor 3. Figure 7.18 shows the temperature distribution on the vertical plane across the fire in the atrium space using 3D plot in FDS. The upper layer temperature in the foyer on Floor 3 does not reach 200^{o}C during the simulation of 1800 s.



(Elevation @ t = 100 s)

(Elevation @ t = 200 s)

(Elevation @ t = 329 s)

Figure 7.17: Smoke development in FDS for fire in the atrium

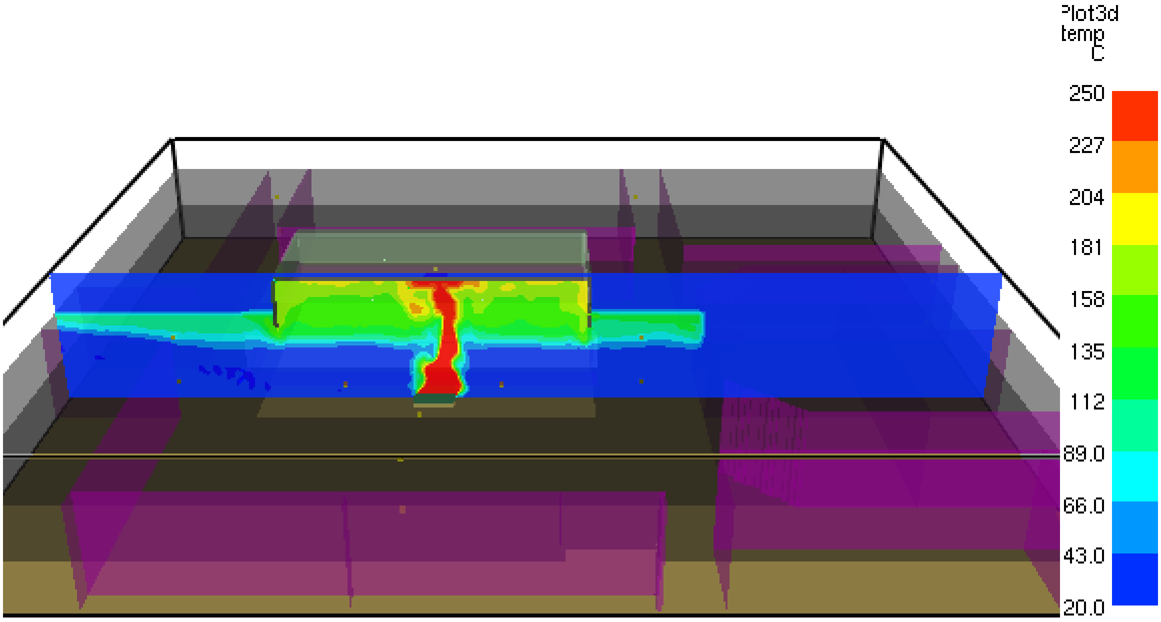


Figure 7.18:3D plot of the temperature distribution for the atrium fire at t=1800s

The results of FDS versus BRANZFIRE are summarised in Table 7.26. The locations of devices in FDS as well as plots at each location are attached in APPENDIX L-6. The results are taken an average where there is more than one device in a space. Only results for Floor 3 (mezzanine floor) are provided here as none of the criteria on Floor 2 is reached in FDS during the simulation time of 1800 s.

Table 7.26: BRANZFIRE vs. FDS for Shopping Mall – Atrium fire

	Criteria	Time Reached (s)		Difference (%)*
		BRANZFIRE	FDS	
Detection Time (s)	-	103 (SD)	81 (SD)	- 14
Floor 3	Visibility = 10 m	329	331	0.6%
	FED Thermal = 0.3	1014	1226	21%
	FED CO = 0.3	>1800	>1800	-

* *A negative value shows criteria is reached earlier in FDS than that in BRANZFIRE*

CHAPTER 8 CASE STUDY 4 - RETAIL WAREHOUSE

8.1 Introduction

Retail warehouse has been a popular topic in the fire engineering industry and a particular concern for stakeholders. This type of buildings is usually a large single storey with mezzanine floor, and contains large quantities of combustible materials, with a high number of occupants present during peak times. The fire safety design can be challenging due to the increasing rack storage height and use of plastics in packaging[79]. The arrangement of stored materials, such as height and aisle widths, may greatly impact the fire spread.

Potential for loss of life depends on the building geometry and the fire hazard of the stored material. In single-storey buildings with low ceilings, smoke may quickly descend below 2.0 m. Where mezzanine floors can be unenclosed, the means of egress may quickly become untenable. Different arrangement and characteristics of the stored commodity may greatly affect the fire behavior. The proposed C/VM2 specifies fire growth rate for three types of commodities as described in Chapter 3. Ingason (2001) [80] have done numerous large scale tests on rack storage fires for several different materials. This case study will be carried out for two types of commodities including:

- Polystyrene chip in single wall cardboard cartons with rack storage height of 5 m;
- FMRC Class II double triwall cardboard cartons with rack storage height of 3 m.

8.2 Building Description

The proposed premise is a single storey retail warehouse with an enclosed mezzanine office floor at the south as shown in Figure 8.1. The warehouse is proposed to be used as retail for building supplies, including retail space, stock room, reception office and drive through on the ground floor; and staff offices, training room, lunch room and toilet facilities on the mezzanine floor. The warehouse ceiling is 8 m high; mezzanine floor is 3.5 m above ground with ceiling height of 2.4 m. The building is 100 mm off boundary at west, 7 m at north, 22 m at east and 30 m at south.

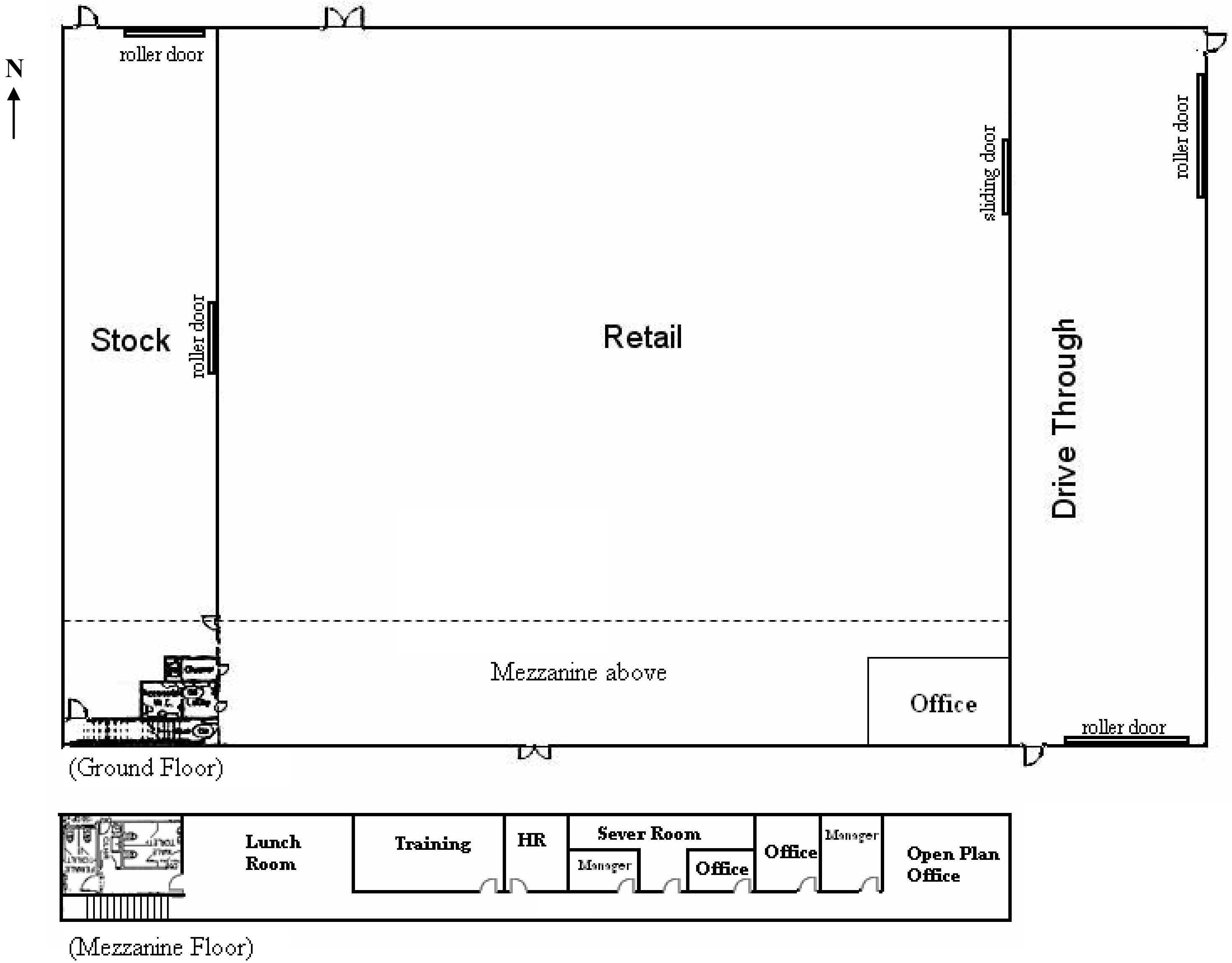


Figure 8.1: Warehouse floor plan

8.3 C/AS1 Design

Where the rack storage height is 3 m with commodity of double triwall cardboard cartons, the building falls in Fire Hazard Category (FHC) 3 in accordance with C/AS1. Where the rack storage height is 5 m with commodity of Polystyrene chip in single wall cardboard cartons, the building falls in FHC 4.

8.3.1 Purpose Groups, Fire Hazard Category and Occupant Loads

The Purpose Group and Fire Hazard Category (FHC) and occupant loads for the retail warehouse are summarised in Table 8.1. The building has total occupants of 236 while majority of the occupants present in the retail area. Total of five cars including 20 passengers can fit in the Drive Through at the same time. Six staff are allowed to have lunch at one time.

Table 8.1: Purpose Group, FHC and Occupant Load

Location		PG	FHC	Occupant Density (persons/m^2)	Area (m^2)	Occupant Load (persons)
Ground Floor	Stock Room	WM / WF	3 / 4	0.03	313	9
	Retail	CM & WM / CM & WF		0.1	1708	171
	Reception	WM/WF		0.1	28	3
	Drive Through	CM		-	409	20
Mezzanine Floor	Open Office	WL	2	0.1	44	4
	Manager 1			0.1	10.5	1
	Office 1			0.1	10.5	1
	Office 2			0.1	6.2	1
	Server Room			0.04	14.8	1
	Manager 2			0.1	6.2	1
	HR			0.1	10.5	1
	Training Room			0.5	34.5	17
	Lunch Room				57.6	6
Total occupant loads of the building						**236**

8.3.2 Requirements for Firecells

For building under FHC 3, the mezzanine floor as well as the staircase shall be enclosed as a smokecell so that the travel distance does not need to be taken as 1.5 times the measured length. For building under FHC 4, the building is divided into three firecells that the ground floor and mezzanine floor shall be treated as separate firecells, and the staircase leading to the mezzanine floor shall be enclosed as a safe path providing egress directly to outside.

For this buildings height and occupancy, the minimum firecel ratings, alarm types and fire safety systems are shown in Table 8.2. As occupant load on the mezzanine floor is less than 50, manual alarm is not required in accordance with *Table 4.1 C/AS1*. Fire Hydrant system is not required as Fire Service hose run distance from vehicular access to any point on any floor is no greater than 75 m. However, to meet the travel distance requirements, smoke detectors are required on both mezzanine floor and ground floor for FHC 3 and sprinkler system is required for FHC 4. This will be further addressed in Section 8.3.3.

Table 8.2: Fire safety precautions – Retail warehouse

Firecell Location	Escape Height (m)	PG	F Rating (minutes)	Alarm Type	Other Protection Required
Ground Floor	0	WM /WF	0	SD (FHC 3) / SPK (FHC 4)	Visibility in escape route
Mezzanine Floor	3.5	WL	0 / 60	SD (FHC 3) / SPK (FHC 4)	Visibility in escape route

Key: SD – Smoke detectors SPK – Sprinklers MCPs – Manual Call Points

The intermediate floor and supporting elements shall have a FRR of no less than 15/15/15 if the area under intermediate floor is unenclosed. As per *Clause 4.5.17 & 6.21.5 C/AS1*, smoke control system may be required in the warehouse containing intermediate floor. However, it may be treated as a single floor firecell and smoke control may be *not* required when:

- The fire hazard category of the firecell is no greater than 3; and
- The occupants load on all intermediate floors is not greater than 100; and
- The total area of the intermediate floors is not greater than 20% of the floor area where the intermediate floors are enclosed.

Therefore, where the retail warehouse is under FHC 3, the occupant load on the intermediate floor is less than 50 and floor area of the enclosed intermediate floor is less than 20 % of the firecell floor area, the building can be treated as a single firecell and smoke control is not required. For FHC 4, the mezzanine floor shall be treated as a separate firecell with F rating of 60 minutes.

For FHC 3, the floor area of an unsprinklered firecell shall not exceed 1500 m^2. The ground floor with floor area over 1500 m^2 does not comply with this requirement. However, as per *Clause 4.2.4 C/AS1*, in an unsprinklered single floor building where the building elements supporting the roof are not fire rated, the firecell floor area may be unlimited provided that no less than 15 % of the roof area (distributed evenly throughout the firecell) is designed for effective roof vent. Therefore the roof is to be provided with 15 % translucent panelling to achieve effective roof venting. For FHC 4, where the building will be sprinklered, the firecell floor area may be unlimited as per *Clause 4.2.5 C/AS1*.

8.3.3 Means of Escape

8.3.3.1 Number and Width of Escape Routes

For FHC 3, the required number and width of escape routes are summarised in Table 8.3. The mezzanine floor is provided with only single means of escape which satisfies the requirements of *Clause 3.15 C/AS1*.

Table 8.3: Width and Number of Escape Routes for the Retail warehouse (FHC 3) unsprinklered

Location		Serving Occupancy (persons)	Number of Egress		Type of Travel	Width (mm)	
			Required	Available		Required	Available
Ground Floor	Stock	9	1	2	H	700	1620
	Retail	171	2	2	H	1197	1620
	Drive Through	23	1	2	H	850	1620
Mezzanine Floor	Open office	4	1	1	H	700	1200
	Manager 1	1	1	1	H	700	810
	Office 1	1	1	1	H	700	810
	Office 2	1	1	1	H	700	810
	Sever room	1	1	1	H	700	810
	Manager 2	1	1	1	H	700	810
	HR	1	1	1	H	700	810
	Training	17	1	1	H	700	810
	Lunch room	6	1	1	H	700	875
	Stair	33	1	1	V	1000	1200
	Stair door	33	1	1	H	875	875

For FHC 4, where the building will be sprinklered, it is not required to provide extra width to allow for the possibility that one escape route may be unusable. The available number and width of escape routes still meet those of C/AS1.

8.3.3.2 Length of Escape Routes

For FHC 3, the maximum escape route lengths are shown below in Table 8.4. While the retail space may contain CM or WM purpose groups, the primary purpose group is CM which requires the shortest maximum allowed travel distance. As per *Clause 3.4.6 C/AS1*, the mezzanine floor has to be enclosed as a smokecell so that the travel distance does not need to be taken as 1.5 times the measured length. The results show that the total length of open path in retail exceeds the maximum allowable distance unless smoke detectors provided which allows 100 % increase, same as on the mezzanine floor. Hence, to meet the requirements for length of escape routes, smoke detectors are required on both ground floor and mezzanine floor.

Table 8.4: Length of Escape Routes for the warehouse (FHC3) unsprinklered

Location		Primary PG	Dead End Open Path (m)		Total Open Path (m)	
			Allowed	Actual	Allowed	Actual
Ground floor	Stock	WM	24 (28.8 with HD) (48 with SD)	0	60 (72 with HD) (120 with SD)	23.8
	Retail	CM	18 (21.6 with HD) (36 with SD)	0	45 (54 with HD) (90 with SD)	69
	Drive Through			0		24.8
Mezzanine floor	Open office	WL	24 (28.8 with HD) (48 with SD)	41.8	60 (72 with HD) (120 with SD)	41.8
	Manager 1			36		36
	Office 1			33.6		33.6
	Office 2			29.6		29.6
	Sever room			28.4		28.4
	Manager 2			25.8		25.8
	HR			23.6		23.6
	Training Room			28.6		28.6
	Lunch room			16.8		16.8

Key: HD – Heat detector SD – Smoke detector

For FHC 4, the maximum escape route lengths are shown below in Table 8.5. The primary purpose group on the ground floor is WF which requires the shortest maximum allowable length. To meet the requirements for length of escape routes, sprinklers are required on the ground floor as no increase allowed for smoke detectors for purpose group WF. To comply with *NZS 4541:2007*[60], the building will be sprinkler protected throughout including the mezzanine floor.

Table 8.5: Length of Escape Routes for the warehouse (FHC4) sprinklered

Location		Primary PG	Dead End Open Path (m)		Total Open Path (m)	
			Allowed	Actual	Allowed	Actual
Ground floor	Stock	WF	24 (48 with SPK)	0	60 (120 with SPK)	23.8
	Retail	WF	18 (36 with SPK)	0	45 (90 with SPK)	69
	Drive Through			0		24.8
Mezzanine floor	Open office	WL	24 (48 with SPK)	41.8	60 (120 with SPK)	41.8
	Manager 1			36		36
	Office 1			33.6		33.6
	Office 2			29.6		29.6
	Sever room			28.4		28.4
	Manager 2			25.8		25.8
	HR			23.6		23.6
	Training Room			28.6		28.6
	Lunch room			16.8		16.8

Key: SPK – Sprinkler

8.3.4 Internal and External Spread of Fire and Smoke

8.3.4.1 Fire Resistance Ratings

As per *Clause 6.9.2 C/AS1*, the safe path stair shall have a FRR greater of F30 or the F rating of the highest rated adjoining firecell. Therefore, for FHC 4, the staircase is required to have a 60/60/60 rating same as mezzanine floor, and fire doors of staircase are to be -/60/60_{Sm} fitted with self closer and vision panels. As the building is sprinklered, the FRR can be reduced by 50 %.

As the building is considered as single firecell under FHC 3 or sprinkler protected under FHC 4, hence it does not required to be protected against vertical fire spread.

The western external wall of the proposed warehouse is 100 mm off boundary which is required to be fire rated. The permitted unprotected area has been calculated using *Method 2 Clause 7.5 C/AS1*. For FHC 3, the permitted unprotected area of western external wall is 12 %. The northern wall is 7 m off boundary which is allowed 24 % unprotected area. The eastern and southern walls are allowed 100 % unprotected area. For FHC 4 where sprinklers are installed, the permitted unprotected area can be doubled.

As per *Clause 7.10.2 C/AS1*, the primary elements of external walls of a building are required to achieve the greater of the F or S rating when the permitted unprotected area in an external wall is restricted due to proximity of the building relevant to the boundary. The *S* rating for the building is shown in Table 8.6. For FHC 3, the western external wall requires a fire resistance rating of 140 minutes and northern wall of 180 minutes. For FHC4, the S rating shall be determined by fire engineering design which is not further addressed here.

Table 8.6: S Rating for external walls for FHC3

Variable	Value	
	Western wall	**Northern wall**
A_v/A_f	<0.05	<0.05
A_h/A_f	0.10	0.05
FHC	3	3
t_e (from *Table 5.1 C/AS1*)	140	180
k	1.0	1.0
S Rating = $k \cdot t_e$	140 minutes	180 minutes

8.3.4.2 Surface Finishes

The exterior and interior surface finishes for this occupancy must meet the requirements of C/AS1 with respect to inhibiting the spread of fire. For FHC 3, the peak rate of heat release and the total heat release from the external wall cladding system shall not exceed the limits as shown in Table 8.7.

This requirement does not apply to surface finishes no more than 1.0 mm in thickness and applied directly to a non-combustible substrate. For FHC 4 where the building is sprinklered, there is no requirement for exterior surface finishes.

Table 8.7: Requirements for External Wall Cladding Systems

Location	PG	Distance to Relevant Boundary	Acceptable Heat Release Rates	
			Peak Rate of Heat Release (kW/m²)	Total Heat Release (MJ/m²)
Western wall of single storey	WL / WM	<1m	100	25
Other walls of single storey	WL/WM/ CM	>1m	No requirement	No requirement

The interior surface finishes of the walls, ceilings, floor linings, and Air ducts shall have surface finishes satisfying the following requirements as shown in Table 8.8.

Table 8.8: Requirements for Surface Finishes - Warehouse

Building Elements	Purpose Group or Location	SFI	SDI	FI
Walls, Ceilings	Exit way	0	3	-
	Purpose group CM where the occupant load is greater than 50	2	5	-
	Passageways, corridors and stairways not being part of an exitway	7	5	-
Flooring (Coverings)	Exitways	Non-combustible or have low radius of effects of ignition		
Ducts for HVAC systems	Internal surfaces	0	3	-
	External surfaces	7	5	-
Suspended flexible fabrics	All occupied spaces including exitways in purpose group CM where occupant load is greater than 50	-	-	12
	Underlay to exterior cladding or roofing when exposed to view in occupied spaces in purpose groups WL, WM, WF, CM and IE	-	-	5
Membrane structures	Purpose groups CM			12

Key: SFI = spread of flame index SDI = smoke developed index FI = flammability index

In firecells constructed without foamed plastics and equipped with sprinklers, only the ceiling needs to comply with the SFI and SDI requirements in the table above. If foamed plastic building materials are used in wall, ceiling or roof systems in either sprinklered or non-sprinklered buildings, they shall meet the requirements in Table 8.9.

Table 8.9: Requirements for foamed plastics materials

Application		Properties CM,WL,WM/WF
FHC 3	Exitways unsprinklered	fb + p
	Non-sleeping occupied spaces unsprinklered	fb + p
	Concealed spaces	p
FHC 4	Exitways sprinklered	fb + p
	Non-sleeping occupied spaces sprinklered	sf + p
	Concealed spaces	p

Key: p – foamed plastics shall comply with the flame propagation criteria as specified in AS 1366
fb – flame barrier complying with Appendix C C9.1 of C/AS1

8.3.5 Fire Fighting

The building provides Fire Service vehicular access within 18 m at north, south and east side of the building. Fire hydrant system does not required as Fire Service vehicular access does not exceed 75 m. In a building not required to have a fire systems centre, the control features shall contain all control panels indicating the status of fire safety systems installed in the building, together with all control switches. Hand operated firefighting equipments, e.g. fire extinguishers, shall be provided and installed in compliance with *NZS 4503:2005 Hand Operated Fire-fighting Equipment*[59].

8.3.6 Summary of Design Features to Comply with C/AS1

The following design features are required to comply with C/AS1:

- For FHC 3, smoke detectors are provided throughout the building. For FHC 4, the building shall be fully sprinklered. All detectors shall be interconnected;
- The intermediate floor shall have FRR of no less than 15/15/15;
- For FHC 3, the western external wall is located 0.1 m from the boundary allowed 12 % unprotected area and requires a fire resistance rating of 140/140/140. The northern wall is located 7 m off the boundary allowed 24 % unprotected area and requires a fire resistance rating of 180/180/180;
- For FHC 3, the mezzanine floor as well as the staircase shall be enclosed as a smokecell. For FHC 4, the mezzanine floor is treated as a firecell having a FRR of 30/30/30. Stairway shall be enclosed as a safe path having same FRR as the mezzanine firecell and provides egress directly to outside;
- For FHC 3, 15% roof area is designed for effective roof vent and shall be evenly distributed;
- All doors on escape routes are designed to open in the direction of escape;
- Emergency lighting is required from the corridor of the mezzanine floor to outside via the staircase and wherever the travel distance to reach one exit is over 20 m on the ground floor;
- Any exit door locking devices should be able to be opened from the inside without the need for a key.

8.4 C/VM2 Analysis

8.4.1 DFS 1 – Challenging Fire

The retail area with occupants over 150, stock and drive through with area greater than 200 m^2 require tenability analysis under DFS 1. All other rooms are less than 200 m^2 and have less than 150 occupants were not analysed. The design fire inputs in the BRANZFIRE modelling have the following parameters shown in Table 8.10 for Rack Storage Group 1 (Polystyrene chip in single wall cardboard cartons) and Group 3 (FMRC Class II double triwall cardboard cartons).

Table 8.10: Design fire parameters in BRANZFIRE modelling – Retail Warehouse

Location	Fire Growth Rate (kW)		Species	Peak HRR (MW)
	Group 3 (FHC3)	Group 1 (FHC4)		
Stock Room			$Y_{soot} = 0.07$	20MW or
Retail			$Y_{CO} = 0.04$	ventilation
Drive Through	$0.00068t^3H$	$0.0088t^3H$	$\triangle H_C = 20MJ/kg$	limit

An example input file in BRANZFIRE for fire in the Retail (FHC 3) with roller doors closed is attached in APPENDIX H-4. The building construction materials for interior walls, ceilings and floors are summarised in Table 8.11.

Table 8.11: Construction materials as modelled in BRANZFIRE – Retail Warehouse

	Wall	Ceiling	Floor
Surface	100mm concrete	6mm steel (mild)	100mm concrete
Substrate	-	-	-

8.4.1.1 ASET - BRANZFIRE Modelling

Figure 8.2 shows the geometry input in BRANZFIRE for fire on the ground floor. The geometry of rooms and details of vents used in BRANZFIRE modelling are given in Table 8.12 and Table 8.13. According to the framework, doors without self-closer shall be modelled as open. However, roller doors are special cases which are not counted as egress routes and may remain closed during the fire. While the roller doors are closed, smoke filling is quicker in the room of fire origin but less smoke spread into other spaces. Whereas, when roller doors are open, they create large open vents allowing smoke spread into adjacent rooms as well as to outside. For a sensitivity study, all roller doors were modelled as both open and close for Group 3 fire while the building is unsprinklered. Roller doors were modelled as closed for Group 1 fire while the building is sprinklered. The material of the roof venting is assumed to be Polycarbonate with melting temperature of 250°C (Harper 2000).

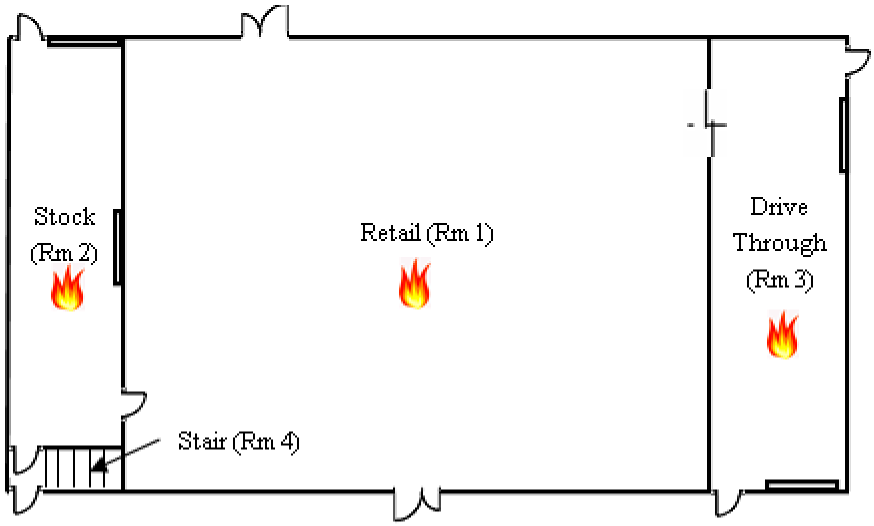


Figure 8.2: Geometry as modeled in BRANZFIRE – Warehouse ground floor

Table 8.12: Geometry of rooms as modeled in BRANZFIRE - Warehouse ground floor

Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height (m)
Retail	1	43.8	37.2	8	0	2
Stock	2	35.6	8.6	8	0	2
Drive through	3	39	10.5	8	0	2
Stair	4	7.5	1.2	5.9	0	5.5

Table 8.13: Geometry of vents as modeled in BRANZFIRE- Warehouse ground floor

Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection (s)
	2	4	0	Roller door	Close / Open	- / Always
	0.81	2	0	Door	Open	Always
1 to 2	0.035	8	0	Leakage	Open	Always
	2	2	0	Sliding door	Self-closing	20
1 to 3	0.035	8	0	Leakage	Open	Always
	0.81	2	0	External	Self-closing	50
	0.81	2	0	External	Self-closing	50
1 to outside	0.063	8	0	Leakage	Open	Always
	0.41	2	0	External	Self-closing	14
2 to Outside	4	4.5	0	Roller door	Close / Open	- / Always
2 to 4	0.44	2	0	Fire door	Self-closing	14
	6	4.5	0	Roller door	Close / Open	- / Always
	6	4.5	0	Roller door	Close / Open	- / Always
	0.053	8	0	Leakage	Open	Always
	0.41	2	0	External	Self-closing	20
3 to Outside	0.41	2	0	External	Self-closing	20
4 to outside	0.44	2	0	External	Self-closing	14

8.4.1.2 ASET Results – BRANZFIRE Modelling

While the building is under FHC 3, only smoke detectors are provided throughout the building. All roller doors were modelled as both open or closed. The BRANZFIRE results are summarised in Table 8.14 and Table *8.15* respectively. The simulations were run for 1800 seconds. All three tenability criteria apply for building without sprinkler system. The case with all roller doors closed results in untenable conditions quicker than the one with roller doors open as the latter has large open vents to outside. None of the criteria was reached in the staircase.

Table 8.14: Summary of BRANZFIRE modelling results for FHC 3 with roller doors open

Fire Location	Spaces	Detection Time (s)	Time to Reach Tenability Criteria (s)			ASET (s)
			FED CO = 0.3	FED Thermal = 0.3	Visibility = 10 m	
Retail fire	Retail	67 (SD)	792	299	270	270
	Stock		1335	564	293	293
	Drive Through		>1800	>1800	>1800	>1800
	Stair		>1800	>1800	>1800	>1800
Stock fire	Retail	68 (SD)	>1800	1723	1243	1243
	Stock		>1800	192	176	176
	Drive Through		>1800	>1800	>1800	>1800
	Stair		>1800	>1800	>1800	>1800
Drive Through fire	Retail	68 (SD)	>1800	>1800	>1800	>1800
	Stock		>1800	>1800	>1800	>1800
	Drive Through		>1800	221	236	221
	Stair		>1800	>1800	>1800	>1800

Table 8.15: Summary of BRANZFIRE modelling results for FHC 3 with roller doors shut

Fire Location	Spaces	Detection Time (s)	Time to Reach Tenability Criteria (s)			ASET (s)
			FED CO = 0.3	FED Thermal = 0.3	Visibility = 10 m	
Retail fire	Retail	67 (SD)	532	295	265	265
	Stock		1580	>1800	356	356
	Drive Through		1558	>1800	415	415
	Stair		>1800	>1800	>1800	>1800
Stock fire	Retail	68 (SD)	>1800	1747	1418	1418
	Stock		551	184	143	143
	Drive Through		>1800	>1800	>1800	>1800
	Stair		>1800	>1800	>1800	>1800
Drive Through fire	Retail	68 (SD)	>1800	>1800	>1800	>1800
	Stock		>1800	>1800	>1800	>1800
	Drive Through		661	197	160	160
	Stair		>1800	>1800	>1800	>1800

While the building is under FHC 4, sprinklers are installed on the ground floor. All roller doors were modelled as closed to maximize the smoke filling. The BRANZFIRE results are summarised in Table 8.16. Only FED CO applies for building sprinklered. Results for FED Thermal and Visibility are also provided for reference.

Table 8.16: Summary of BRANZFIRE modelling results for FHC 4 with roller doors shut

Location	Spaces	Detection Time (s)	Time to Reach Tenability Criteria (s) FED CO = 0.3	FED Thermal = 0.3	Visibility = 10 m	ASET (s)
Retail fire	Retail	77 (SPK)	429	297	191	429
	Stock		1015	>1800	288	1015
	Drive Through		1010	>1800	341	1010
	Stair		>1800	>1800	>1800	>1800
Stock fire	Retail	70 (SPK)	954	1157	535	954
	Stock		173	91	73	173
	Drive Through		>1800	>1800	1080	>1800
	Stair		>1800	>1800	>1800	>1800
Drive Through fire	Retail	71 (SPK)	1768	>1800	1134	1768
	Stock		>1800	>1800	>1800	>1800
	Drive Through		207	100	82	207
	Stair		>1800	>1800	>1800	>1800

8.4.1.3 RSET Results

All occupants in the building are considered to be awake at the time of the fire and, as it is a public building, occupants in retail and drive through areas are assumed to be unfamiliar with the building layout and possible escape routes. Staff in stock and mezzanine offices are considered familiar with escape routes. RSET results for fire in Retail, Stock and Drive Through on the ground floor are provided in Table 8.17 to Table 8.19 for each fire location. For occupants who are unfamiliar with the building layout, the pre-movement time is 60 s for room of fire origin and 120 s elsewhere. Staff who are away from the fire origin have pre-movement time of 60 s. The travel time for retail area is governed by queuing whilst travel in other spaces is governed by walking.

Table 8.17: RSET results for fire in Retail

Events	Time (s)
Group 3 fire (FHC 3) in Retail	
Time to detection: t_d	67s (SD)
Time for pre-movement: t_p	60s for occupants in Retail (fire origin) and Stock 120s for occupants in Drive Through
Time for travel / flow : t_t	129s clear Retail (queuing govern) 20s clear Stock (walking govern) 21s clear Drive Through (walking govern)
RSET for clear Retail (fire origin)	= $t_d + t_p + t_t$ =67s+60s+129s=256s
RSET for clear Stock	= $t_d + t_p + t_t$ =67s+60s+20s=147s
RSET for clear Drive Through	= $t_d + t_p + t_t$ =67s+120s+21s=208s
Group 1 fire (FHC 4) in Retail	
Time to detection: t_d	77s (SPK)
RSET for clear Retail (fire origin)	= $t_d + t_p + t_t$ =77s+60s+129s=266s
RSET for clear Stock	= $t_d + t_p + t_t$ =77s+60s+20s=157s
RSET for clear Drive Through	= $t_d + t_p + t_t$ =77s+120s+21s=218s

Table 8.18: RSET results for fire in Stock

Events	Time (s)
Group 3 fire (FHC 3) in Stock	
Time to detection: t_d	68s (SD)
Time for pre-movement: t_p	30s for occupants in stock (fire origin) 120s for occupants in Retail & Drive Through
Time for travel / flow : t_t	129s clear Retail (queuing govern) 20s clear Stock (walking govern) 21s clear Drive Through (walking govern)
RSET for clear Stock (fire origin)	= $t_d + t_p + t_t$ =68s+30s+20s=118s
RSET for clear Retail	= $t_d + t_p + t_t$ =68s+120s+129s=317s
RSET for clear Drive Through	= $t_d + t_p + t_t$ =68s+120s+21s=209s
Group 1 fire (FHC 4) in Stock	
Time to detection: t_d	70s (SPK)
RSET for clear Stock (fire origin)	= $t_d + t_p + t_t$ =70s+30s+20s=120s
RSET for clear Retail	= $t_d + t_p + t_t$ =70s+120s+129s=319s
RSET for clear Drive Through	= $t_d + t_p + t_t$ =70s+120s+21s=211s

Table 8.19: RSET results for fire in Drive Through

Events	Time (s)
Group 3 fire (FHC 3) in Drive Through	
Time to detection: t_d	68s (SD)
Time for pre-movement: t_p	60s for occupants in Drive Through (fire origin) and Stock; 120s for occupants in Retail
Time for travel / flow : t_t	129s clear Retail (queuing govern) 20s clear Stock (walking govern) 21s clear Drive Through (walking govern)
RSET for clear Drive Through (fire origin)	= $t_d + t_p + t_t$ =68s+60s+21s=149s
RSET for clear Retail	= $t_d + t_p + t_t$ =68s+120s+129s=317s
RSET for clear Stock	= $t_d + t_p + t_t$ =68s+60s+20s=148s
Group 1 fire (FHC 4) in Drive Through	
Time to detection: t_d	71s (SPK)
RSET for clear Drive Through (fire origin)	= $t_d + t_p + t_t$ =71s+60s+21s=152s
RSET for clear Retail	= $t_d + t_p + t_t$ =71s+120s+129s=320s
RSET for clear Stock	= $t_d + t_p + t_t$ =71s+60s+20s=151s

8.4.1.4 RSET vs. ASET

(1) FHC 3 – Roller doors open

Where the building is unsprinklered with a Group 3 design fire and all roller doors were modelled as open, the results for RSET, ASET and the safety margin are summarised in Table 8.20 to Table 8.22 for each fire location. The design meets the C/VM2 criteria.

Table 8.20: RSET vs. ASET results for Group 3 (FHC 3) fire in Retail with roller doors open

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Retail (fire origin tenability)			
RSET		256	-
ASET	Visibility = 10 m	270	14
	FED Thermal = 0.3	299	43
	FED CO = 0.3	792	536
Stock			
RSET		147	-
ASET	Visibility = 10 m	293	146
	FED Thermal = 0.3	564	417
	FED CO = 0.3	1335	1188
Drive Through			
RSET		208	-
ASET	Visibility = 10 m	>1800	>1592
	FED Thermal = 0.3	>1800	>1592
	FED CO = 0.3	>1800	>1592

Table 8.21: RSET vs. ASET results for Group 3 (FHC 3) fire in Stock with roller doors open

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Stock (fire origin tenability)			
RSET		118	-
ASET	Visibility = 10 m	176	58
ASET	FED Thermal = 0.3	192	74
ASET	FED CO = 0.3	>1800	>1682
Retail			
RSET		317	-
ASET	Visibility = 10 m	1243	926
ASET	FED Thermal = 0.3	1723	1406
ASET	FED CO = 0.3	>1800	>1483
Drive Through			
RSET		209	-
ASET	Visibility = 10 m	>1800	>1591
ASET	FED Thermal = 0.3	>1800	>1591
ASET	FED CO = 0.3	>1800	>1591

Table 8.22: RSET vs. ASET results for Group 3 (FHC 3) fire in Drive Through with roller doors open

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Drive Through (fire origin tenability)			
RSET		149	-
ASET	Visibility = 10 m	236	87
ASET	FED Thermal = 0.3	221	72
ASET	FED CO = 0.3	>1800	>1651
Retail			
RSET		317	-
ASET	Visibility = 10 m	>1800	>1483
ASET	FED Thermal = 0.3	>1800	>1483
ASET	FED CO = 0.3	>1800	>1483
Stock			
RSET		148	-
ASET	Visibility = 10 m	>1800	>1652
ASET	FED Thermal = 0.3	>1800	>1652
ASET	FED CO = 0.3	>1800	>1652

(2) FHC 3 – Roller doors shut

Where the building is unsprinklered with a Group 3 design fire and all roller doors were modelled as closed, the results for RSET versus ASET and the safety margin are summarised in Table 8.23 to Table 8.25 for each fire location. The design meets the C/VM2 criteria but with a safety margin of only 11 s for fire in the Drive Through.

Table 8.23: RSET vs. ASET results for Group 3 (FHC 3) fire in Retail with roller doors shut

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Retail (fire origin tenability)			
RSET		256	-
ASET	Visibility = 10 m	265	9
	FED Thermal = 0.3	295	39
	FED CO = 0.3	532	276
Stock			
RSET		147	-
ASET	Visibility = 10 m	356	209
	FED Thermal = 0.3	>1800	>1653
	FED CO = 0.3	1580	1433
Drive Through			
RSET		208	-
ASET	Visibility = 10 m	415	207
	FED Thermal = 0.3	>1800	>1592
	FED CO = 0.3	1558	1350

Table 8.24: RSET vs. ASET results for Group 3 (FHC 3) fire in Stock with roller doors shut

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Stock (fire origin tenability)			
RSET		118	-
ASET	Visibility = 10 m	143	25
	FED Thermal = 0.3	184	66
	FED CO = 0.3	551	433
Retail			
RSET		317	-
ASET	Visibility = 10 m	1418	1101
	FED Thermal = 0.3	1747	1430
	FED CO = 0.3	>1800	>1483
Drive Through			
RSET		209	-
ASET	Visibility = 10 m	>1800	>1591
	FED Thermal = 0.3	>1800	>1591
	FED CO = 0.3	>1800	>1591

Table 8.25: RSET vs. ASET results for Group 3(FHC 3) fire in Drive Through with roller doors shut

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Drive Through (fire origin tenability)			
RSET		149	-
ASET	Visibility = 10 m	160	11
ASET	FED Thermal = 0.3	197	48
ASET	FED CO = 0.3	661	512
Retail			
RSET		317	-
ASET	Visibility = 10 m	>1800	>1483
ASET	FED Thermal = 0.3	>1800	>1483
ASET	FED CO = 0.3	>1800	>1483
Stock			
RSET		148	-
ASET	Visibility = 10 m	>1800	>1652
ASET	FED Thermal = 0.3	>1800	>1652
ASET	FED CO = 0.3	>1800	>1652

(3) FHC 4 – Roller doors shut

Where the building is sprinklered with a Group 1 design fire and all roller doors were modelled as closed, the results for RSET versus ASET and the safety margin are summarised in Table 8.26 to Table 8.28 for each fire location. Only FED CO applies for occupant tenability. The design meets the C/VM2 criteria.

Table 8.26: RSET vs. ASET results for Group 1 (FHC 4) fire in Retail with roller doors shut

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Retail (fire origin tenability)			
RSET		266	-
ASET	Visibility = 10 m	191	***-75*** (N/A)
ASET	FED Thermal = 0.3	297	31 (N/A)
ASET	FED CO = 0.3	429	163
Stock			
RSET		157	-
ASET	Visibility = 10 m	288	131 (N/A)
ASET	FED Thermal = 0.3	>1800	>1643 (N/A)
ASET	FED CO = 0.3	1015	858
Drive Through			
RSET		218	-
ASET	Visibility = 10 m	341	123 (N/A)
ASET	FED Thermal = 0.3	>1800	>1582 (N/A)
ASET	FED CO = 0.3	1010	792

*Values shown in **bold italic** show that RSET exceeds the ASET* *N/A – Not applicable*

Table 8.27: RSET vs. ASET results for Group 1 (FHC 4) fire in Stock with roller doors shut

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Stock (fire origin tenability)			
RSET		120	-
ASET	Visibility = 10 m	73	***-47*** (N/A)
ASET	FED Thermal = 0.3	91	***-29*** (N/A)
ASET	FED CO = 0.3	173	53
Retail			
RSET		317	-
ASET	Visibility = 10 m	535	218 (N/A)
ASET	FED Thermal = 0.3	1157	840 (N/A)
ASET	FED CO = 0.3	954	637
Drive Through			
RSET		211	-
ASET	Visibility = 10 m	1080	869 (N/A)
ASET	FED Thermal = 0.3	>1800	>1589 (N/A)
ASET	FED CO = 0.3	>1800	>1589

*Values shown in **bold italic** show that RSET exceeds the ASET N/A – Not applicable*

Table 8.28: RSET vs. ASET results for Group 1 (FHC 4) fire in Drive Through with roller doors shut

Criteria		Time Reached (s)	Margin = ASET - RSET (s)
Drive Through (fire origin tenability)			
RSET		152	-
ASET	Visibility = 10 m	82	***-70*** (N/A)
ASET	FED Thermal = 0.3	100	***-52*** (N/A)
ASET	FED CO = 0.3	207	55
Retail			
RSET		320	-
ASET	Visibility = 10 m	1134	814 (N/A)
ASET	FED Thermal = 0.3	>1800	>1480 (N/A)
ASET	FED CO = 0.3	1768	1448
Stock			
RSET		151	-
ASET	Visibility = 10 m	>1800	>1649 (N/A)
ASET	FED Thermal = 0.3	>1800	>1649 (N/A)
ASET	FED CO = 0.3	>1800	>1649

*Values shown in **bold italic** show that RSET exceeds the ASET N/A – Not applicable*

8.4.2 DFS 2 – Blocked Exit

The mezzanine floor with occupant loads less than 50 is allowed to have single means of escape. All other spaces have at least two egress routes equally sized. This scenario is achieved.

8.4.3 DFS 3 – Fire in Unoccupied Room

The fire safety precautions for this building include a fully analogue addressable detection system or sprinkler system installed throughout the building which satisfies this scenario.

8.4.4 DFS 4 – Fire in Concealed Space

The fire safety precautions for this building include a fully analogue addressable detection system or sprinkler system installed throughout the building which satisfies this scenario.

8.4.5 DFS 5 – Smouldering Fire

There is no requirement to test this scenario in the warehouse building where no sleeping occupants present. Therefore, this scenario is achieved.

8.4.6 DFS 6 – Fire Spread to Other Property

The building complies with the requirements of Part 7 of C/AS1 as detailed in Section 8.3.4. This scenario is achieved.

8.4.7 DFS 7 – Vertical External Fire Spread

The building does not have sleeping occupants or 'other property' on upper floors and building height is less than 10 m. Therefore, this scenario does not apply.

8.4.8 DFS 8 – Interior Surface Finishes

This scenario applies to all buildings except that the smoke production rate criterion is not required for sprinkler protected buildings. The surface finishes of walls and ceilings in the safe path staircase and mezzanine floor will be plasterboard or concrete (Group 1 materials), achieving a time to flashover not less than 20 minutes. It satisfies Performance Measure 1. Walls and ceilings on the ground floor, and floor surfaces of the building will be concrete which is non-combustible. This scenario is achieved.

8.4.9 DFS 9 – Fire Service Operations

According to the framework, firefighter tenability must be established for:

- Large FHC 4 buildings (>1500 m^2) regardless if the building is sprinklered; or
- Unsprinklered buildings where the distance from the safe path access to any point on a floor exceeds 75 m.

As the warehouse building has floor area of 2500 m^2, firefighter tenability analysis may be required. For FHC 3, the distance from street access to any point in the warehouse does not exceed 75 m. Firefighter tenability analysis is not required. For FHC 4, firefighter tenability analysis is required that the design shall meet the criteria described in Section 3.8.2.

As the distance from street access to any point in the warehouse does not exceed 75 m, firefighters are expected to operate for a short period of time with direct thermal radiation. The following criteria for heat/smoke exposure shall be achieved:

- Maximum ambient temperature ≤ 120°C; and
- Maximum radiation ≤ 3 kW/m^2; and
- Maximum time of exposure ≤ 10 minutes.

Based on previous analysis in DFS 1, results for the ambient temperature and radiation are summarised in Table 8.29 for room of fire origin. For fire in Stock, the first criterion reached is radiation which exceeds 3 kW/m^2 after 90 s. The ambient temperature exceeds 120°C after 202 s. The design does not meet firefighter tenability criteria.

Table 8.29: Results of ambient temperature and radiation for Group 1(FHC 3) fire with sprinkler

Fire location	Time Reached in room of fire origin (s)	
	Ambient temperature = 120°C	**radiation = 3 kW/m^2**
Retail	362	331
Stock	202	90
Drive Through	265	103

It has been aware that the proposed C/VM2 gives parameters of sprinklers in Table 3.9 for most general cases. However, for special building features such as warehouse with high rack storage and ultra fast fire growth rate, parameters of sprinklers used in the analysis may comply with the requirements in *NZS 4541 Automatic Fire Sprinkler Systems*[60].

8.4.10 DFS 10 – Robustness Check

The objective of this scenario is to do a robustness check with each key fire safety system rendered in effective in turn, including smoke management systems, and fire and/or smoke doors. Fire sprinklers and automatic fire alarms complied with New Zealand Standard are considered to be sufficiently reliable. The building does not have smoke control system, and three fire doors within the safe path staircase serve less than 50 occupants; therefore, Scenario 10 does not apply to this building.

8.5 Summary of Safety Margin for DFS 1

8.5.1 FHC 3 – Roller doors open

For FHC 3, fire protection systems include smoke detectors throughout the building. All roller doors remained open in the analysis. Only results for room of fire origin are provided here in Figure 8.3. The design meets the current C/VM2 for DFS 1 with safety factor of 1.1. The most critical fire location is for fire in the retail.

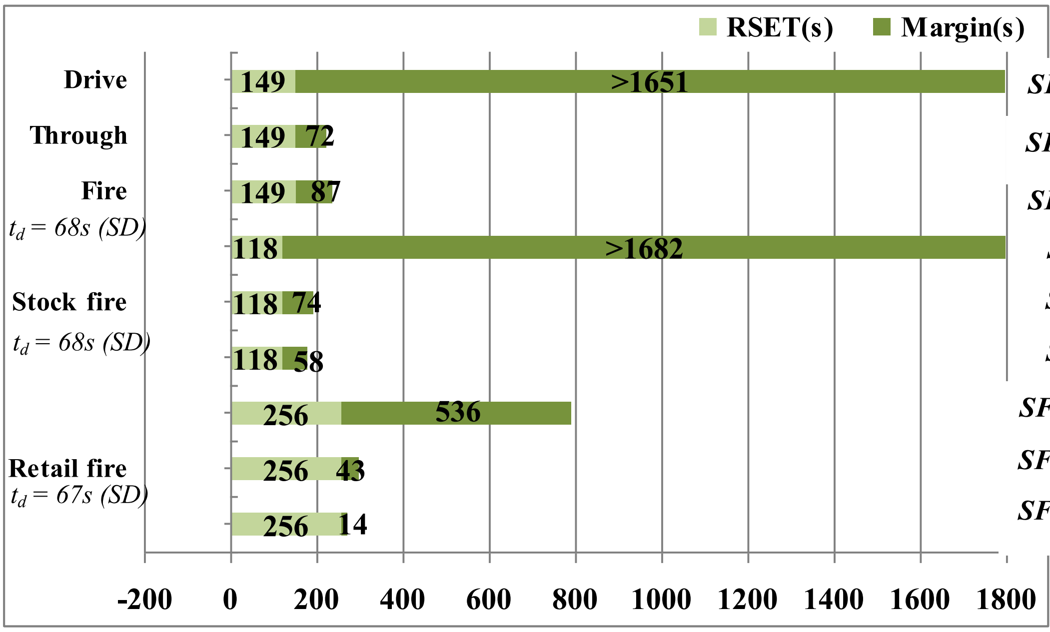


Figure 8.3: Warehouse (FHC 3) safety margin for room of fire origin – roller doors open

8.5.2 FHC 3 – Roller doors shut

Fire protection systems include smoke detectors throughout the building. All roller doors remained closed in the analysis. Only results for room of fire origin are provided here in Figure 8.4. The design meets the current C/VM2 for DFS 1 with safety factor of 1.0. The most critical fire location is for fire in the retail.

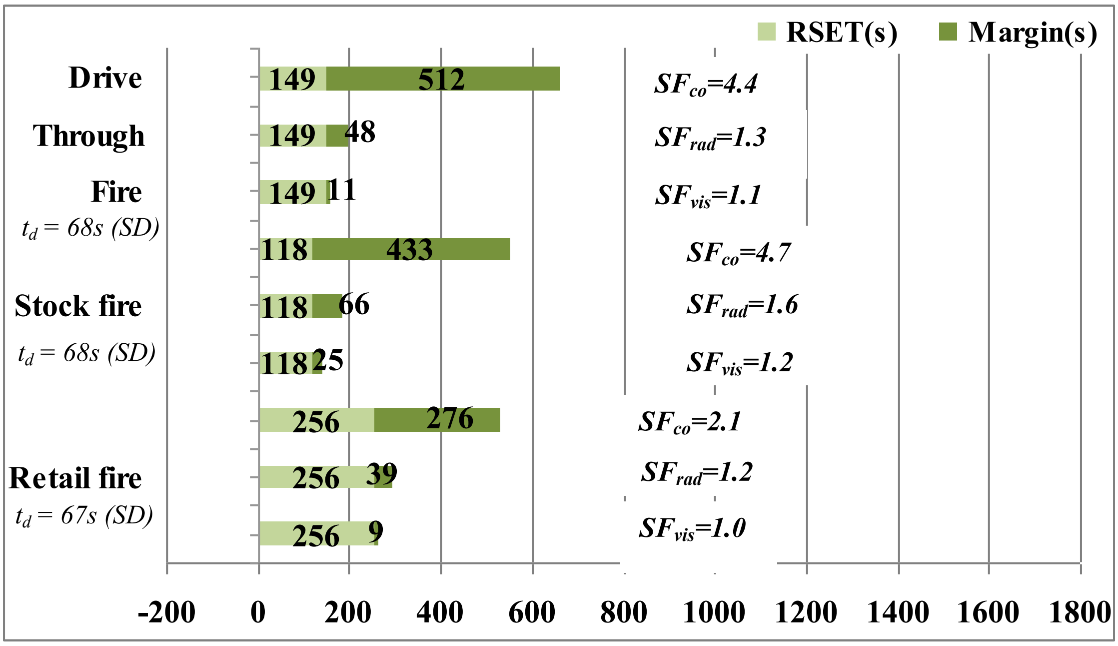


Figure 8.4: Warehouse (FHC 3) safety margin for room of fire origin – roller doors shut

8.5.3 FHC 4 – Roller doors shut

For FHC 4, fire protection systems include sprinklers throughout the building. All roller doors remained closed in the analysis. Only results for room of fire origin are provided here in Figure 8.5. The design meets the current C/VM2 with safety factor of 1.4.

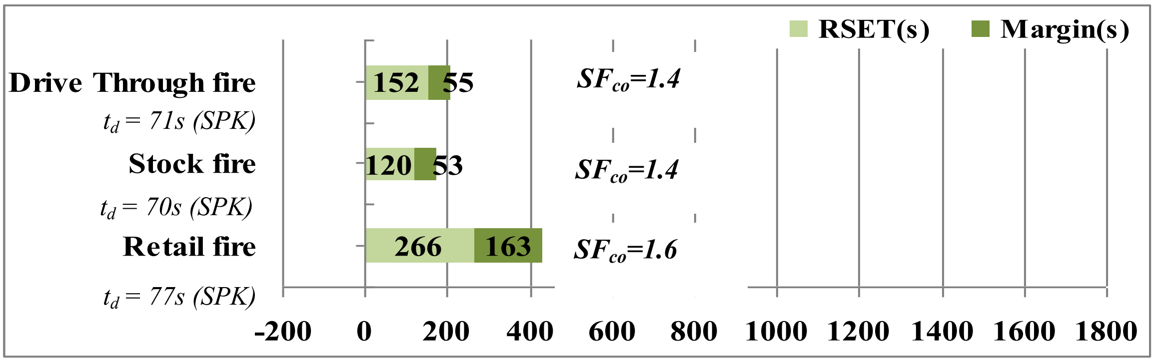


Figure 8.5: Warehouse (FHC 4) safety margin for room of fire origin – roller doors shut

8.6 Discussion

As mentioned in Section 6.7, the current Design Fire Scenario 1 only applies for room / space greater than 200 m^2 or with over 150 occupants. It may not apply to a building or a firecell if there is no room greater than 200 m^2 or with over 150 occupants, such as the mezzanine office firecell in the Retail Warehouse. It has been suggested that at least one fire should be modelled in each firecell except for firecells of safe path or intermittent activity. Hence, a fire in the open office on the mezzanine floor was modelled in the BRANZFIRE as shown in Figure 8.6.

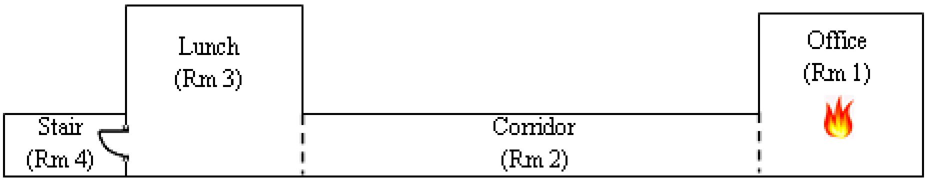


Figure 8.6: Geometry as modelled in BRANZFIRE – Warehouse mezzanine floor

The geometry of rooms and vents are provided in Table 8.30 and Table 8.31. The office is assumed to have a window opening to the south of 2 m wide by 1 m high which is assumed to break at either 500°C or when the fire becomes ventilation controlled whichever occurs sooner. The interior construction material is assumed to be concrete. The design fire has a fast growth rate up to ventilation controlled. The floor is provided with smoke detectors without sprinkler system.

Table 8.30: Geometry of rooms as modeled in BRANZFIRE - Warehouse mezzanine floor

Room	#	Length (m)	Width (m)	Height (m)	Elevation (m)	Motoring Height (m)
Office	1	8	5.5	2.4	3.5	2
Corridor	2	26	1.2	2.4	3.5	2
Lunch	3	10.5	5.5	2.4	3.5	2
Stair	4	7.5	1.2	5.9	0	5.5

Table 8.31: Geometry of vents as modeled in BRANZFIRE- Warehouse mezzanine floor

Vent	Width (m)	Height (m)	Sill (m)	Function	Open/ Self-closing	Door Open Duration after Detection (s)
1 to 2	1.2	2.4	0	Open wall	Open	Always
1 to outside	2	1	1	Window	-	-
2 to 3	1.2	2.4	0	Open wall	Open	Always
3 to 4	0.44	2	0	Leakage	Open	44

The modelling results show that the fire became ventilation controlled at 248 s and the maximum heat release was 2900 kW. The smoke detector activated at 50 s after ignition. Staff on the mezzanine floor shall be awake and alert who are familiar with the egress routes. They will start evacuation within 30 s after the alarm sounds. According to the egress calculation, it takes 49 s for all occupants to evacuate from the mezzanine floor into the staircase, which is governed by walking. The detailed results for RSET versus ASET are summarised in Table 8.32. In the office room of fire origin, visibility was the first criterion reached which dropped below 5 m in 31 s before occupants start evacuation. Whereas, the other two criteria for FEDs have been satisfied.

Table 8.32: RSET vs. ASET results for a fast fire in mezzanine office

<table>
<tr><th colspan="2">Criteria</th><th>Time Reached (s)</th><th>Margin = ASET - RSET (s)</th></tr>
<tr><td colspan="2">Time to detection: t_d</td><td colspan="2">50 (SD)</td></tr>
<tr><td colspan="2">Time for pre-movement: t_p</td><td colspan="2">30</td></tr>
<tr><td colspan="2">Time for travel / flow : t_t</td><td colspan="2">11s to clear office (Walking govern)
49s to clear mezzanine floor</td></tr>
<tr><td colspan="4">Room of fire origin (Office tenability)</td></tr>
<tr><td colspan="2">RSET for clear office (fire origin)</td><td colspan="2">= $t_d + t_p + t_t$ = 50 + 30 + 11 = 91s</td></tr>
<tr><td rowspan="3">ASET</td><td>Visibility = 5 m</td><td>31</td><td>- 60</td></tr>
<tr><td>FED Thermal = 0.3</td><td>123</td><td>32</td></tr>
<tr><td>FED CO = 0.3</td><td>216</td><td>125</td></tr>
<tr><td colspan="4">Firecell of fire origin (Lunch tenability)</td></tr>
<tr><td colspan="2">RSET for clear mezzanine floor</td><td colspan="2">= $t_d + t_p + t_t$ = 50 + 30 + 49 = 129s</td></tr>
<tr><td rowspan="3">ASET</td><td>Visibility = 5 m</td><td>99</td><td>-30</td></tr>
<tr><td>FED Thermal = 0.3</td><td>554</td><td>425</td></tr>
<tr><td>FED CO = 0.3</td><td>412</td><td>283</td></tr>
</table>

Values shown in ***bold italic*** *show that RSET exceeds the ASET* *N/A – Not applicable*

8.7 Sensitivity Analysis

8.7.1 Group 3 design fire – 5m rack (FHC4) with roller doors shut

In this case, the rack storage height is increased from 3 m to 5 m for Group 3 design fire. Then, the building is categorised as FHC 4 as the heat release rate is greater than 1 MW in 75 s. To meet the travel distance requirements in C/AS1, the building requires sprinkler system. To check if the proposed C/VM2 provides a similar level of safety as C/AS1, only smoke detector was used in the analysis without sprinkler system. If the design still meets the C/VM2 criteria, it will result in a lower level of safety than that of C/AS1. The ASET and RSET results for rooms of fire origin are summarised in Table 8.33 and Table 8.34.

Table 8.33: ASET results for room of fire origin – Group 3 design fire with 5 m rack (FHC 4) with roller doors shut & unsprinklered

Fire Location	Time to Reach Tenability Criteria (s)			ASET (s)
	FED CO = 0.2	FED Thermal = 0.3	Visibility = 10 m	
Retail fire	508	271	245	245
Stock fire	538	163	127	127
Drive Through fire	645	171	143	143

Table 8.34: RSET results for room of fire origin – Group 3 design fire with 5 m rack (FHC 4) with roller doors shut & unsprinklered

Fire Location	Detection Time(s)	Pre-movement Time(s)	Travel Time(s)	RSET(s)
Retail fire	59	60	129	248
Stock fire	61	30	20	111
Drive Through fire	60	60	21	141

The results for RSET vs. ASET and the safety margin are provided in Figure 8.7. The design without sprinkler system does not meet the current C/VM2 criteria for fire in the retail area due to the visibility. Hence, C/VM2 does not allow incompliance with C/AS1 which means C/VM2 does not provide lower level of safety than that of C/AS1 as expected.

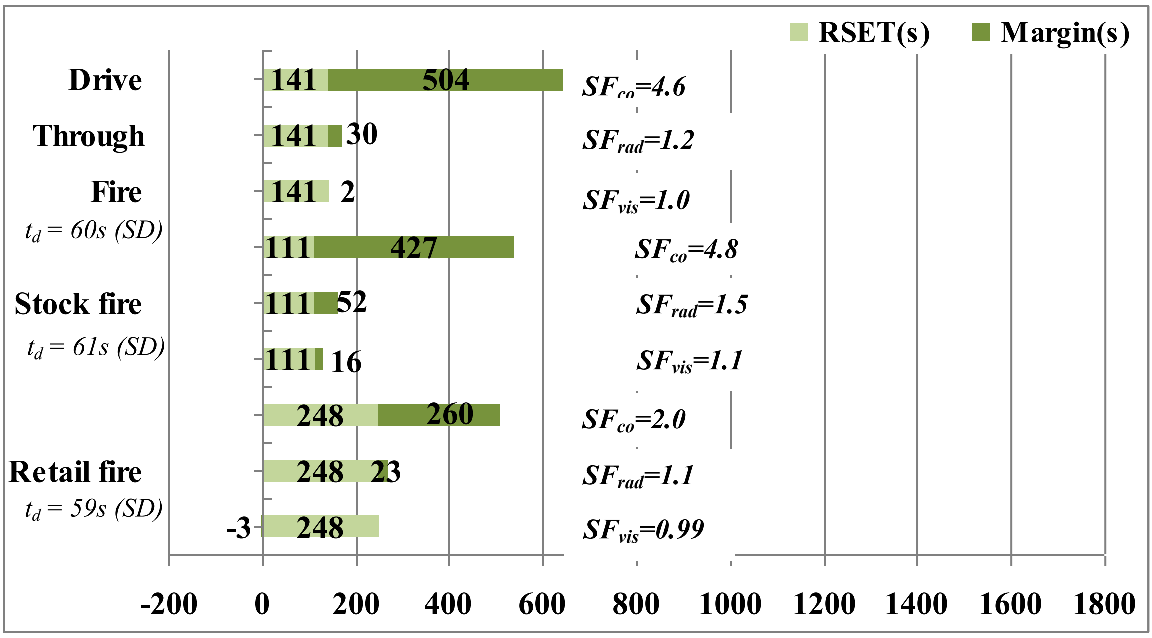


Figure 8.7: RSET vs. ASET for Group 3 design fire (FHC 4) with 5m rack roller doors shut - unsprinklered

8.7.2 Group 1 design fire – 3m rack (FHC4) with roller doors shut

In this case, the rack storage height is decreased from 5 m to 3 m for Group 1 design fire. The building is still under FHC 4 as the heat release rate is greater than 1 MW in 75 s. To meet the travel distance requirements by C/AS1, the building will requires sprinkler system. To check if the proposed C/VM2 provides a similar level of safety as C/AS1, only smoke detector was used in the analysis without sprinkler system. The ASET and RSET results for rooms of fire origin are summarised in Table 8.35 and Table 8.36.

Table 8.35: ASET results for room of fire origin – Group 1 design fire with 3 m rack (FHC 4) with roller doors shut & unsprinklered

Fire Location	Time to Reach Tenability Criteria (s)			ASET (s)
	FED CO = 0.2	FED Thermal = 0.3	Visibility = 10 m	
Retail fire	456	216	192	192
Stock fire	472	96	81	81
Drive Through fire	584	104	90	90

Table 8.36: RSET results for room of fire origin – Group 1 design fire with 3 m rack (FHC 4) with roller doors shut & unsprinklered

Fire Location	Detection Time(s)	Pre-movement Time(s)	Travel Time(s)	RSET(s)
Retail fire	37	60	129	226
Stock fire	39	30	20	89
Drive Through fire	38	60	21	119

The results for RSET vs. ASET and the safety margin are provided in Figure 8.8. The design without sprinkler system does not meet the current C/VM2 criteria for fire at each location. Hence, C/VM2 does not allow incompliance with C/AS1 which means C/VM2 does not provide lower level of safety than that of C/AS1 as expected.

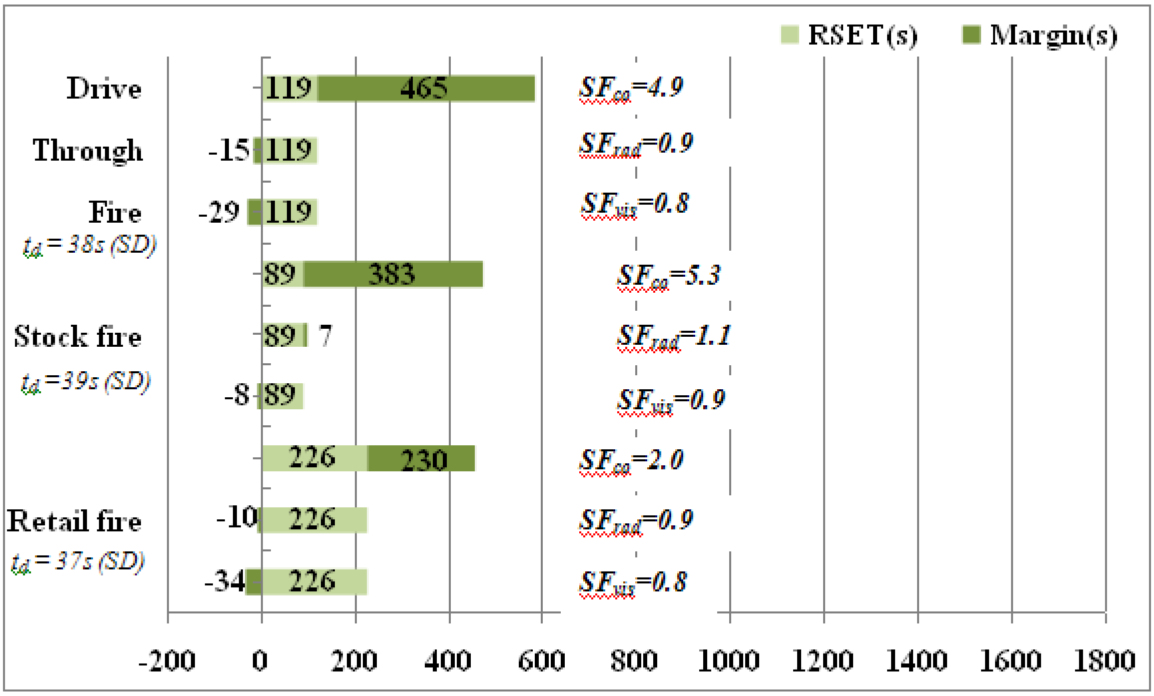


Figure 8.8: RSET vs. ASET for Group 1 design fire (FHC 4) with 3m rack roller doors shut - unsprinklered

8.8 FDS vs. BRANZFIRE

The graphic layout of the warehouse building in Smokeview is shown in Figure 8.9. The fire was chosen to be located in the Drive Through with Group 3 design fire and 5 m rack storage height same as the case in Section 8.7.1. All roller doors were modelled as closed and sprinkler system was rendered to be ineffective. Roof venting was provided over the Drive Through and opened once temperature reaches 250°C. A grid size of 200 mm was used in the Drive Through of fire origin whilst 400 mm grid size was used elsewhere.

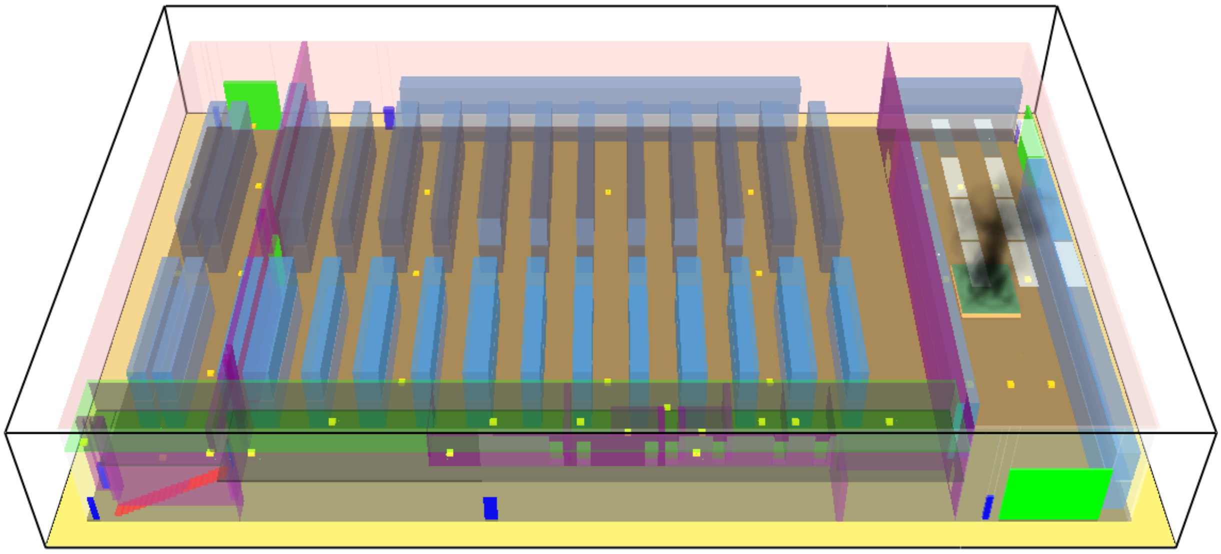
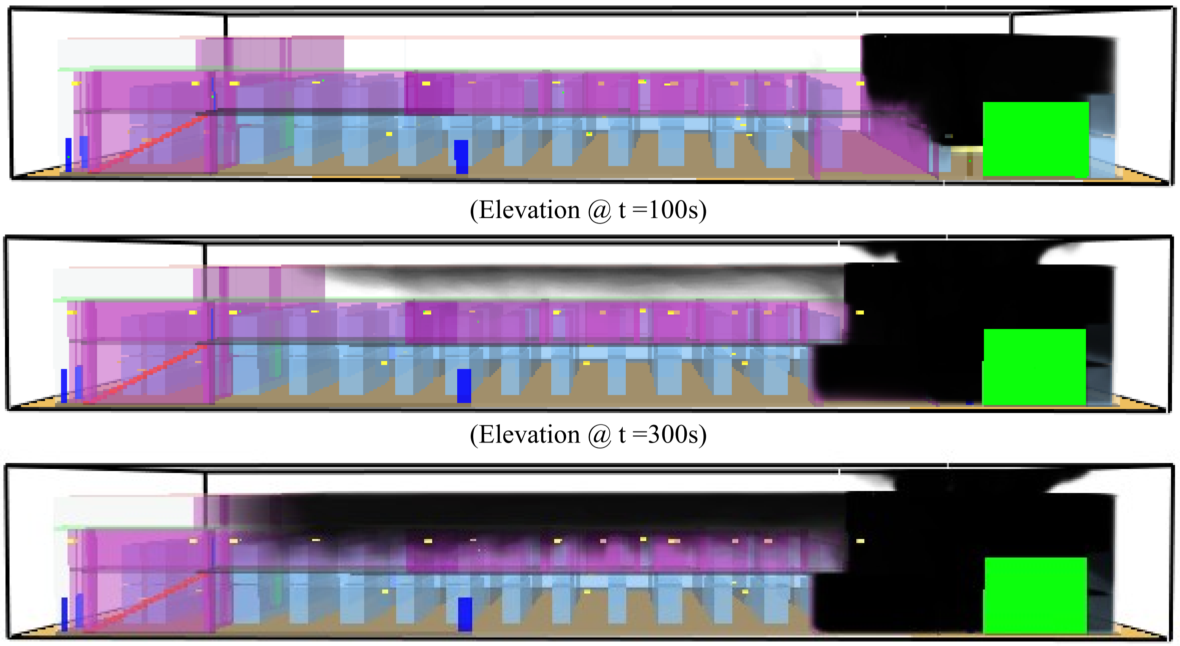


Figure 8.9: Warehouse layout in Smokeview

Figure 8.10 shows the smoke movement for fire in the drive through. The smoke layer quickly descended until the Polycarbonate roof vents reached 250°C at 263 s and opened since then. The smoke spilled into the retail space via the open sliding door. However, the smoke layer did not drop dramatically in the retail space due to the large volume of smoke reservoir over the space.



(Elevation @ t =100s)

(Elevation @ t =300s)

(Elevation @ t =900s)

Figure 8.10: Smoke development in FDS for fire in the drive through

The results of FDS versus BRANZFIRE are summarised in Table 8.37 for room of fire origin only as criteria in other spaces were not reached. The FDS results are taken an average where there is more than one device in a space. The locations of devices in FDS as well as plots at each location are attached in APPENDIX L-7. FDS provides quite different results compared to BRANZFIRE. In FDS, the FED Thermal reaches 0.3 after 284 s compared to 171 s in BRANZFIRE. FED CO does not reach 0.3 in 900 s compared to 645 s in BRANZFIRE. This may be due to the ineffective roof venting in BRANZFIRE modelling. According to Figure 8.11, the smoke layer in BRANZFIRE drops to 1.4 m above floor after the roof venting open whilst layer height in FDS fluctuated almost above 2 m.

Table 8.37: BRANZFIRE vs. FDS for Warehouse – Drive Through fire

	Criteria	Time Reached (s)		Difference (%)
		BRANZFIRE	**FDS**	
Detection Time (s)	-	60 (SD)	46 (SD)	23
Time for roof venting open (s)	-	200	263	31
Room of fire origin (Drive Through)	Visibility = 10 m	143	123	14
	FED Thermal = 0.3	171	284	66
	FED CO = 0.3	645	>900	-

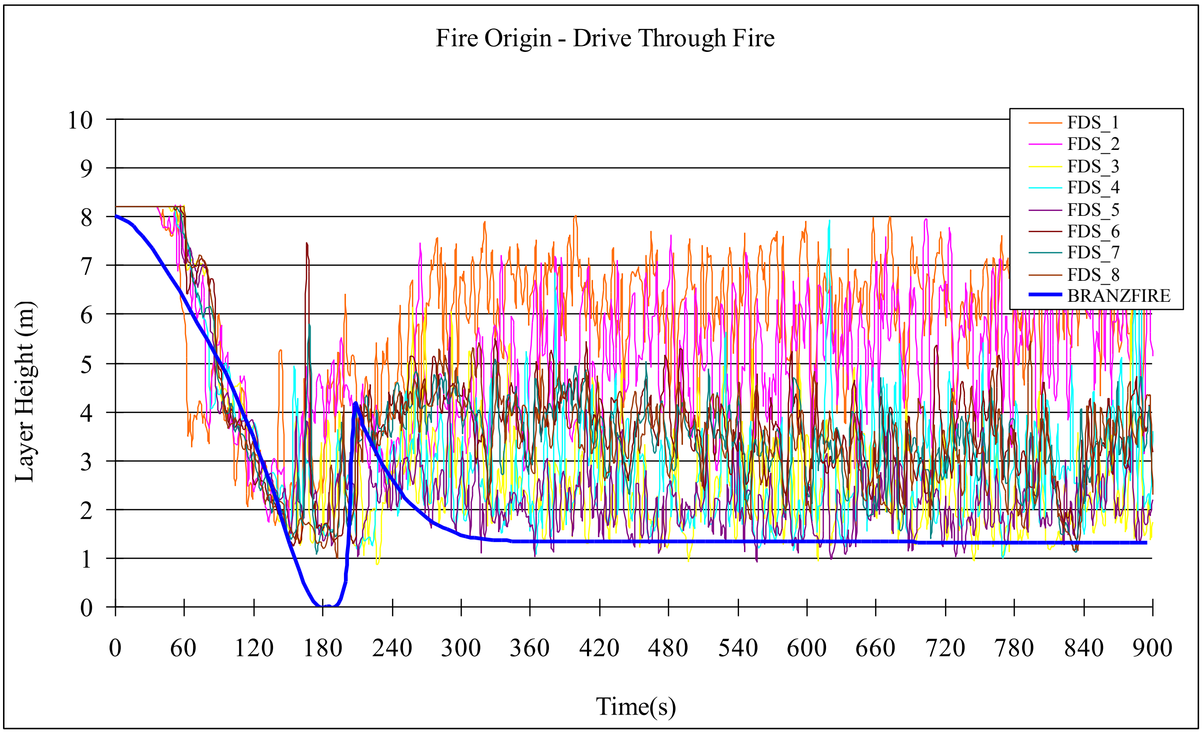


Figure 8.11: Smoke layer height for Group 3 design fire (FHC 4) in Drive Through with 5m rack roller doors shut - unsprinklered

CHAPTER 9 CONCLUSIONS & RECOMMENDATIONS

This report has provided detailed analyses and results of four complex case study buildings to evaluate the appropriateness of the proposed Verification Method C/VM2 compared to the level of safety inherent in the prescriptive document C/AS1. The proposed C/VM2 is expected to introduce greater transparency and less ambiguity for fire engineering designs through explicit guidance on fire scenarios, design fire inputs, evacuation parameters and performance criteria to be met in order for the design to be deemed compliant with the Building Code. In general, it successfully implements a systematic and less ambiguous guidance for performance-based fire design in the future. It impels the decision on what is the acceptable level of safety moved from individuals to the authorities.

In general, through intensive analyses, the proposed C/VM2 provides reasonable good consistence with C/AS1 that all case study buildings pass the performance measurements pre-described in C/VM2 with the achieved safety factor of 1.0. In some measure, C/VM2 has more strict requirements on the visibility criterion where the building is not sprinkler protected; on the other hand, it has loose criteria for buildings with sprinkler system. It is also required more details on the egress calculation, e.g. minimum required number of exits. Besides, it has not provided a detailed design solution for hospital buildings. The following sections provide more detailed findings through the four case studies.

9.1 Nightclub

There are two design strategies provided for the nightclub fire design including both prescriptive (C/AS1) design and performance-based design. The checklists of compliance for each fire scenario are provided in Table 9.1 for building designed under C/AS1 including both sprinklered and unsprinklered designs.

Table 9.1: Checklist of compliance for the nightclub building

	Scenarios	Comply(Y/N)	Comments
Without Sprinkler	DFS 1 – Challenging Fire	N	Visibility fails
	DFS 2 – Blocked Exit	Y	-
	DFS 3 – Fire in Unoccupied Room	Y	-
	DFS 4 – Fire in Concealed Space	Y	-
	DFS 5 – Smouldering Fire	Y	-
	DFS 6 – Fire Spread to Other Property	Y	-
	DFS 7 – Vertical External Fire Spread	Y	-
	DFS 8 – Interior Service Operations	Y	-

	Scenarios	Comply(Y/N)	Comments
	DFS 9 – Fire Service Operations	Y	-
	DFS 10 – Robustness Check	Y	-
With Sprinkler	DFS 1 – Challenging Fire	Y	Pass with safety factor of 1.0
	DFS 2 – Blocked Exit	Y	-
	DFS 3 – Fire in Unoccupied Room	Y	-
	DFS 4 – Fire in Concealed Space	Y	-
	DFS 5 – Smouldering Fire	Y	-
	DFS 6 – Fire Spread to Other Property	Y	-
	DFS 7 – Vertical External Fire Spread	Y	-
	DFS 8 – Interior Service Operations	Y	-
	DFS 9 – Fire Service Operations	Y	-
	DFS 10 – Robustness Check	Y	-

Even though, C/AS1 allows the nightclub to be unsprinklered, large floor area shall be modified to provide sufficient egress for the full occupant loads as well as a sound stage evacuation scheme which are hardly to be achieve and costly. Hence, the best solution to comply with C/AS1 is to provide sprinkler system throughout the building so that widths of egress routes do not required to be increased. To meet the proposed C/VM2 criteria for a performance-based design, the nightclub must be sprinklered as well as increasing width of final exits on the ground floor to achieve a safety factor of 1.0. Hence, C/VM2 may result in a slightly higher level of safety than that of C/AS1 which is desirable to take into account any uncertainties using new technologies or methodologies in the performance-based design.

Compared to the other three case study buildings, the nightclub building has the most crowded occupancy and complex egress routes but least volume for smoke filling, which exposes some findings of the current C/VM2. It gives over conservative results for visibility which is often the first criteria reached in room of fire origin. The visibility often drops below 5 m even before occupants start evacuation, which means a general office building will not pass the C/VM2 criteria if the building is unsprinklered. However, this may not be undesirable since the intention of the framework is not to take over C/AS1 which is still the priority solution to be used. Verification Method only applies when a building has features that cannot be designed under the prescriptive solution. The higher requirements for visibility brings the benefit to make sure simple structured buildings, which can be designed straight forward under the prescriptive documents (C/AS1), will not pass the C/VM2 criteria. On the other hand, for large space with lower occupant density, e.g. warehouse, the design can still meet the visibility criteria without sprinkler system. For small space with high occupant density, e.g. nightclub, the best practice is to provide sprinkler system that visibility is not required to be assessed. This encourages use of sprinkler systems in high hazard buildings.

Design Fire Scenario 1 requires the most analysis in a performance-based design. There are some suggestion including: firstly, the current Design Fire Scenario 1 only applies for room or space greater than 200 m^2 or with over 150 occupants. It may not apply to a firecell / building if there is no room greater than 200 m^2 or with over 150 occupants, such as the mezzanine floor in the Retail Warehouse and the patient room firecells in the Hospital do not require tenability analysis under DFS 1. The suggestion is maybe at least one fire modelled in each firecell except for firecells of safe path or intermittent activity; secondly, readers may notice that for the nightclub building, the Dance Floor by the main exit originally has less than 150 occupants and has a floor area less than 200 m^2 which does not required analysis under DFS 1. However, results show that it becomes the most critical fire location as occupants from other spaces will egress through the Dance floor and out of the building via the main exit. Therefore, it is suggested that DFS 1 shall be revised to apply for room or space serving more than 150 occupants and provide supporting activities to those occupants. (It does not apply to spaces, e.g. corridors and stairs, serving more than 150 occupants but not providing functional activity to those occupants.)

The proposed C/VM2 may over benefit buildings with sprinkler system: firstly, only FED CO applies for performance criteria that visibility and FED Thermal are not required to be assessed; secondly, robustness check does not apply to sprinkler systems which are considered sufficiently reliable. The suggestion is to increase the safety factor to be achieved from 1.0 to 2.0 for FED CO where the building is sprinklered. Section 5.8 gives the performance-based design solutions for the nightclub building with achieved safety factor of 1.0, 1.5 and 2.0 respectively. To achieve a higher safety factor greater than 1.0, smoke detectors are often required for early warning, and/or increase widths of egress routes.

9.2 Hosptial

The fire design philosophy in a hospital is relatively simple that a complex hospital will require sprinkler system as well as smoke detectors in patient sleeping area. The checklists of compliance for each fire scenario are provided in Table 9.2 for the hospital designed under C/AS1.

Table 9.2: Checklist of compliance for the hospital building

Scenarios	Comply(Y/N)	Comments
DFS 1 – Challenging Fire	Y	Pass with safety factor of 1.9
DFS 2 – Blocked Exit	Y	-
DFS 3 – Fire in Unoccupied Room	Y	-
DFS 4 – Fire in Concealed Space	Y	-
DFS 5 – Smouldering Fire	Y	-
DFS 6 – Fire Spread to Other Property	Y	-
DFS 7 – Vertical External Fire Spread	Y	-

Scenarios	Comply(Y/N)	Comments
DFS 8 – Interior Service Operations	Y	-
DFS 9 – Fire Service Operations	Y	-
DFS 10 – Robustness Check	Y	-

Evacuation process of a hospital can be complicate. Different occupant characteristics and patient-to-staff ratios can result in different evacuation requirements. Because some patients are incapable of movement, spaces such as surgical theatres are required to remain functional in the event of fire. Patients in intensive care unit (ICU) are often connected to various life support devices, making movement very difficult and time-consuming. The proposed C/VM2 does not provide detailed guideline for the egress calculation for people with disability or under care. On the other hand, C/AS1 requires where group sleeping area for patients is contained within one firecell, the number of beds shall not exceed 12, or 6 if the group sleeping area is sub-divided into suite such as rest homes for the elderly. The proposed C/VM2 does not have such compartmentation requirements.

Some additional analysis has been carried out for patient room fire scenario. This study used the criteria that FED for CO shall not be greater than 0.2 for patients who are prone to toxic smoke. The staff to patient ratio is around 1:4 for most general cases (higher value shall be used for critical ill patients, e.g. ICU). The travel speed for moving a patient along the corridor is 0.6 m/s. The staff response time is 30 s and it takes about 40 s to prepare a patient for movement. Assuming a travel distance of 45 m along the corridor, it takes an average of 2.5 minutes (excluding detection time) to move a patient out of the ward. The results show that patient group sleeping area with over 12 beds requires to be subdivided into two firecells by fire separation. This is based on the assumption that only one staff is required to move a patient. However, more staff are often expected to assist evacuation of a critical ill patient and the time frame to prepare a patient for movement is much longer when patients are connected to various life supporting devices.

9.3 Shopping Mall

The checklists of compliance for each fire scenario are provided in Table 9.3 for the shopping mall designed under C/AS1. The design meets the current C/VM2 with safety factor of 3.5 under DFS 1.

Table 9.3: Checklist of compliance for the shopping mall

Scenarios	Comply(Y/N)	Comments
DFS 1 – Challenging Fire	Y	Pass with safety factor of 3.5
DFS 2 – Blocked Exit	Y	-
DFS 3 – Fire in Unoccupied Room	Y	-
DFS 4 – Fire in Concealed Space	Y	-
DFS 5 – Smouldering Fire	Y	-

Scenarios	Comply(Y/N)	Comments
DFS 6 – Fire Spread to Other Property	Y	-
DFS 7 – Vertical External Fire Spread	Y	-
DFS 8 – Interior Service Operations	Y	-
DFS 9 – Fire Service Operations	Y	-
DFS 10 – Robustness Check	Y	-

In the event of fire in a shopping mall, occupants must evacuate the premise as quickly and orderly as possible through use of multiple exits. Under the prescriptive solution, *Table 3.1 C/AS1* provides the minimum required number of escape routes from a floor level. The shopping mall, with over 5000 occupants on each floor, requires at least 6 egress routes in accordance with C/AS1. While the current C/VM2 only requires two exits which is governed by DFS 2: Blocked Exit. If a fire may put a large number of people at risk, it is considered appropriate to include additional safety factors within the design. As discussed before, it is considered that the proposed C/VM2 over benefits buildings with sprinkler system that a safety factor greater than 1.0 (e.g. 2.0) shall be achieved for FED CO where the building is sprinklered. It is also suggested that where a firecell containing more than 5000 occupants, a safety factor of 2.0 shall be achieved for FED CO as well as robustness check is required with sprinkler system rendered ineffective. This will bring up more strict requirements on egress routes for assembly buildings with a large number of occupants, unfamiliar with egress routes, crowded in one space/firecell.

The current C/VM2 says the pre-movement times can be reduced half in firecell of fire origin, which may give too much benefit when a firecell has large floor area, e.g. shopping mall, or several floors containing in one atrium firecell. The suggestion is that pre-movement times may be only reduced half for firecells with working business activities where occupants are familiar with each other, or firecells with open plan.

9.4 Retail Warehouse

Several cases have been analysed for the retail warehouse with different rack storage groups of different heights. The checklists of compliance for each fire scenario are provided in Table 9.4 for building under FHC 3 with Group 3 design fire and Table 9.5 for building under FHC 4 with Group 1 design fire.

Results show that C/VM2 provides good consistence with C/AS1 that all cases, no matter roller doors open or close, pass the C/VM2 performance criteria with achieved safety factor of 1.0 for building under FHC 3 without sprinkler system. For warehouse under FHC 4 with sprinkler system, the design passes the C/VM2 performance criteria except for DFS 10 that the design does not pass firefighter tenability criteria.

Table 9.4: Checklist of compliance for the retail warehouse – FHC 3 (without sprinkler)

Scenarios	Comply (Y/N)	Comments
DFS 1 – Challenging Fire	Y	Pass with safety factor of 1.1 for roller doors modelled as open or 1.0 if closed
DFS 2 – Blocked Exit	Y	-
DFS 3 – Fire in Unoccupied Room	Y	-
DFS 4 – Fire in Concealed Space	Y	-
DFS 5 – Smouldering Fire	Y	-
DFS 6 – Fire Spread to Other Property	Y	-
DFS 7 – Vertical External Fire Spread	Y	-
DFS 8 – Interior Service Operations	Y	-
DFS 9 – Fire Service Operations	Y	-
DFS 10 – Robustness Check	Y	-

Table 9.5: Checklist of compliance for the retail warehouse – FHC 4 (with sprinkler)

Scenarios	Comply (Y/N)	Comments
DFS 1 – Challenging Fire	Y	Pass with safety factor of 1.4 for roller doors modelled as closed
DFS 2 – Blocked Exit	Y	-
DFS 3 – Fire in Unoccupied Room	Y	-
DFS 4 – Fire in Concealed Space	Y	-
DFS 5 – Smouldering Fire	Y	-
DFS 6 – Fire Spread to Other Property	Y	-
DFS 7 – Vertical External Fire Spread	Y	-
DFS 8 – Interior Service Operations	Y	-
DFS 9 – Fire Service Operations	**N**	Fail for firefighter tenability criteria
DFS 10 – Robustness Check	Y	-

For the sensitivity study, the warehouse has been modelled as unsprinklered even though sprinkler system is required by C/AS1. Results show that it does not pass the C/VM2 criteria, which means C/VM2 does not allow incompliance with C/AS1, or C/VM2 does not provide lower level of safety than that of C/AS1.

The continued analysis and development is necessary for a sound systematic verification method for performance-based fire engineering design. Even though there is no easy answer, the question of how detailed the performance-based designs to be regulated shall be answered before such a document is developed. One of the advantages of performance-based design over prescriptive requirements is its variation and flexibility, and thus the benefit of cost effective, whereas the disadvantage of giving too much freedom to individuals. Hence, the author feels it is vital to reach mutual agreement between designers and regulators to keep the balance of flexibility and cost-effectiveness while providing consistent level of safety and regulatory control for specific engineering design in the long term. It is suggested that the verification documents shall be developed in a balanced way where verification procedure and methods are specified for more consistent level of safety, as well as remain innovation and flexibility of fire engineering designs, thus not over limit the freedom of designers and disturbing the technological development. Hence, a solely deterministic method may not be the best solution that a risk-based concept is suggested to be incorporated into the new generation of the C/VM2.

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APPENDIX A New Zealand Building Code C1, C2, C3, C4

FIRST SCHEDULE—*continued*

Clause C1—OUTBREAK OF FIRE

Provisions	Limits on application
OBJECTIVE	
C1.1 The objective of this provision is to safeguard people from injury or illness caused by *fire*.	
FUNCTIONAL REQUIREMENT	
C1.2 In *buildings* fixed appliances using the controlled combustion of solid, liquid or gaseous fuel, shall be installed in a way which reduces the likelihood of *fire*.	
PERFORMANCE	
C1.3.1 Fixed appliances and services shall be installed so as to avoid the accumulation of gases within the installation and in *building* spaces, where heat or ignition could cause uncontrolled combustion or explosion.	
C1.3.2 Fixed appliances shall be installed in a manner that does not raise the temperature of any *building element* by heat transfer or concentration to a level that would adversely affect its physical or mechanical properties or function.	

FIRST SCHEDULE–*continued*

Clause C2–MEANS OF ESCAPE

Provisions	Limits on application
OBJECTIVE **C2.1** The objective of this provision is to: (a) Safeguard people from injury or illness from a *fire* while escaping to a *safe place*, and (b) Facilitate *fire* rescue operations. **FUNCTIONAL REQUIREMENT** **C2.2** *Buildings* shall be provided with *means of escape from fire* which: (a) Give people *adequate* time to reach a *safe place* without being overcome by the effects of *fire*, and (b) Give fire service personnel *adequate* time to undertake rescue operations. **PERFORMANCE** **C2.3.1** The number of *open paths* available to each person escaping to an *exitway* or *final exit* shall be appropriate to: (a) The *travel distance*. (b) The number of occupants, (c) The *fire hazard*, and (d) The *fire safety systems* installed in the *firecell*. **C2.3.2** The number of *exitways* or *final exits* available to each person shall be appropriate to: (a) The *open path travel distance*, (b) The *building height*, (c) The number of occupants, (d) The *fire hazard*, and (e) The *fire safety systems* installed in the *building*. **C2.3.3** *Escape routes* shall be: (a) Of *adequate* size for the number of occupants,	

FIRST SCHEDULE–*continued*

Provisions	Limits on application
(b) Free of obstruction in the direction of escape,	Performance C2.3.3(b) must not prevent a door that forms part of an *escape route* from being locked if the person who locks it is satisfied that no-one is in that part of the *building* served by the *escape route* and that no one is likely to enter that part of the *building*, except in an emergency, without unlocking that door.
(c) Of length appropriate to the mobility of the people using them,	
(d) Resistant to the spread of *fire* as required by Clause C3 "Spread of Fire",	
(e) Easy to find as required by Clause F8 "Signs",	
(f) Provided with systems for visibility during failure of the main lighting, as required by Clause F6 "Visibility in escape routes", and	
(g) Easy and safe to use as required by Clause D1.3.3 "Access Routes".	

FIRST SCHEDULE–*continued*

Clause C3–SPREAD OF FIRE

Provisions	Limits on application
OBJECTIVE	
C3.1 The objective of this provision is to:	
(a) Safeguard people from injury or illness when evacuating a *building* during *fire*.	
(b) Provide protection to fire service personnel during firefighting operations.	
(c) Protect adjacent *household units*, other residential units, and *other property* from the effects of *fire*.	
(d) Safeguard the environment from adverse effects of *fire*.	
FUNCTIONAL REQUIREMENT	
C3.2 *Buildings* shall be provided with safeguards against *fire* spread so that:	
(a) Occupants have time to escape to a *safe place* without being overcome by the effects of *fire*,	
(b) Firefighters may undertake rescue operations and protect property,	
(c) Adjacent *household units*, other residential units, and *other property* are protected from damage, and	
(d) Significant quantities of *hazardous substances* are not released into the environment during *fire*.	Requirement C3.2(d) applies only to *buildings* where significant quantities of *hazardous substances* are stored and processed.
PERFORMANCE	
C3.3.1 Interior surface finishes on walls, floors, ceilings and suspended *building elements*, shall resist the spread of *fire* and limit the generation of toxic gases, smoke and heat, to a degree appropriate to:	
(a) The *travel distance*,	
(b) The number of occupants,	

FIRST SCHEDULE–*continued*

Provisions	Limits on application
(c) The *fire hazard*, and	
(d) The active *fire safety systems* installed in the *building*.	
C3.3.2 *Fire separations* shall be provided within *buildings* to avoid the spread of *fire* and smoke to:	
(a) Other *firecells*,	
(b) Spaces intended for sleeping, and	Performance C3.3.2(b) does not apply to *Detached Dwellings* or within *household units* of *Multi-unit Dwellings*.
(c) *Household units* within the same *building* or *adjacent buildings*.	
(d) *Other property*.	
C3.3.3 *Fire separations* shall:	
(a) Where openings occur, be provided with *fire resisting closures* to maintain the *integrity* of the *fire separations* for an *adequate* time, and	
(b) Where penetrations occur, maintain the *fire resistance rating* of the *fire separation*.	
C3.3.4 *Concealed spaces* and cavities within *buildings* shall be sealed and subdivided where necessary to inhibit the unseen spread of *fire* and smoke.	Performance C3.3.4 shall not apply to *Detached Dwellings*.
C3.3.5 *External walls* and roofs shall have resistance to the spread of *fire*, appropriate to the *fire load* within the *building* and to the proximity of other *household units*, other residential units and *other property*.	
C3.3.6 Automatic *fire* suppression systems shall be installed where people would otherwise be:	
(a) Unlikely to reach a safe place in *adequate* time because of the number of storeys in the *building*,	
(b) Required to remain within the *building* without proceeding directly to a *final exit*, or where the *evacuation time* is excessive,	

FIRST SCHEDULE–*continued*

Provisions	Limits on application
(c) Unlikely to reach a *safe place* due to confinement under institutional care because of mental or physical disability, illness or legal detention, and the *evacuation time* is excessive, or	
(d) At high risk due to the *fire load* and *fire hazard* within the *building*.	
C3.3.7 Air conditioning and mechanical ventilation systems shall be constructed to avoid circulation of smoke and *fire* between *firecells*.	
C3.3.8 Where an automatic smoke control system is installed, it shall be constructed to:	
(a) Avoid the spread of *fire* and smoke between *firecells*, and	
(b) Protect *escape routes* from smoke until the occupants have reached a *safe place*.	
C3.3.9 The *fire safety systems* installed shall facilitate the specific needs of fire service personnel to:	
(a) Carry out rescue operations, and	
(b) Control the spread of *fire*.	
C3.3.10 Environmental protection systems shall ensure a low probability of *hazardous substances* being released to:	Performance C3.3.10 applies only to *buildings* where significant quantities of *hazardous substances* are stored or processed.
(a) Soils, vegetation or natural waters,	
(b) The atmosphere, and	
(c) *Sewers* or public *drains*.	

FIRST SCHEDULE—*continued*

Clause C4—STRUCTURAL STABILITY DURING FIRE

Provisions	Limits on application
OBJECTIVE	
C4.1 The objective of this provision is to:	
(a) Safeguard people from injury due to loss of structural stability during *fire*, and	
(b) Protect *household units* and *other property* from damage due to structural instability caused by *fire*.	
FUNCTIONAL REQUIREMENT	
C4.2 *Buildings* shall be constructed to maintain structural stability during *fire* to:	
(a) Allow people *adequate* time to evacuate safely,	
(b) Allow fire service personnel *adequate* time to undertake rescue and firefighting operations, and	
(c) Avoid collapse and consequential damage to adjacent *household units* or *other property*.	
PERFORMANCE	
C4.3.1 Structural elements of *buildings* shall have *fire* resistance appropriate to the function of the elements, the *fire load*, the *fire intensity*, the *fire hazard*, the height of the *buildings* and the *fire* control facilities external to and within them.	
C4.3.2 Structural elements shall have a *fire* resistance of no less than that of any element to which they provide support within the same *firecell*.	
C4.3.3 Collapse of elements having lesser *fire* resistance shall not cause the consequential collapse of elements required to have a higher *fire* resistance.	

APPENDIX B C/AS1 Table 2.1 Purpose Groups

Table 2.1: Purpose Groups
Paragraphs 1.3.4, 2.1.3, 2.2.1, 2.2.10, 5.6.11 and 5.6.13

Purpose group	Description of intended use of the building space	Some examples	Fire hazard category
CROWD ACTIVITIES			
CS or CL	For *occupied spaces*. CS applies to *occupant loads* up to 100 and CL to *occupant loads* exceeding 100.	Cinemas when classed as CS, art galleries, auditoria, bowling alleys, churches, clubs (non-residential), community halls, court rooms, dance halls, day care centres, gymnasia, lecture halls, museums, eating places (excluding kitchens), taverns, enclosed grandstands, indoor swimming pools.	1
		Cinemas when classed as CL, schools, colleges and tertiary institutions, libraries (up to 2.4 m high book storage), nightclubs, restaurants and eating places with cooking facilities, *early childhood centres theatre* stages, opera houses, television studios (with audience).	2
		Libraries (over 2.4 m high book storage).	3
CO	Spaces for viewing open air activities (does not include spaces below a grandstand).	Open grandstands, roofed but unenclosed grandstand, uncovered fixed seating.	1
CM	Spaces for displaying, or selling retail goods, wares or merchandise.	Exhibition halls, retail shops. 2 Supermarkets or other stores with bulk storage/display over 3.0 m high.4	
SLEEPING ACTIVITIES			
SC	Spaces in which *principal users* because of age, mental or physical limitations require special care or treatment.	Hospitals. Care institutions for the aged, children, *people with disabilities*.	1
SD	Spaces in which *principal users* are restrained or liberties are restricted.	Care institutions, for the aged or children, with physical restraint or detention. Hospital with physical restraint, detention quarters in a police station, prison.	1
SA	Spaces provided for the use of people who will be transient and reside for a temporary period, typically not more than 90 days, or where limited assistance or care is provided for *principal users*.	Motels, hotels, hostels, boarding houses, clubs (residential), boarding schools, dormitories, halls of residence, *wharenui*, community care institutions.	1
SR	Attached and multi-unit residential dwellings.	*Multi-unit dwellings* or flats, apartments, and includes *household units* attached to the same or other *purpose groups*, such as caretakers' flats, and residential accommodation above a shop. *Household unit firecells* may contain garages which are used exclusively by the occupants of that *household unit*. Excludes sleeping accommodation used for a temporary period typically no more than 90 days	1
SH	Detached dwellings where people live as a single household or family.	Dwellings, houses, being *household units*, or *suites* in *purpose group* SA, separated from each other by distance. Detached dwellings may include attached self-contained *suites* such as granny flats when occupied by a member of the same family, and garages whether detached or part of the same *building* and are primarily for storage of the occupants' vehicles, tools and garden implements.	1

Table 2.1: Purpose Groups *(continued)*

Purpose group	Description of intended use of the building space	Some examples	Fire hazard category
WORKING, BUSINESS OR STORAGE ACTIVITIES			
WL	Spaces used for working, business or storage – low *fire load.*	Manufacturing, processing or storage of *non-combustible* materials, or materials having a slow heat release rate, cool stores, covered cattle yards, wineries, grading or storage or packing of horticultural products, wet meat processing.	1
		Banks, hairdressing shops, beauty parlours, personal or professional services, dental offices, laundry (self-service), medical offices, business or other offices, police stations (without detention quarters), radio stations, television studios (no audience), small tool and appliance rental and service, telephone exchanges, dry meat processing.	2
WM	Spaces used for working, business or storage – medium *fire load* and slow/medium/fast *fire* growth rates (e.g. <1 MW in 75 sec) **(Note 1)**.	Manufacturing and processing of *combustible* materials not otherwise listed, including bulk storage up to 3 m high (excluding *foamed plastics*).	3
WH	Spaces used for working, business or storage – high *fire load* and slow/medium/ fast *fire* growth rates (e.g. <1 MW in 75 sec) **(Note 1)**.	Chemical manufacturing or processing plants, distilleries, feed mills, flour mills, lacquer factories, mattress factories, rubber processing plants, spray painting operations, plastics manufacturing, bulk storage of *combustible* materials over 3 m high (excluding *foamed plastics*).	4
WF	Spaces used for working, business or storage – medium/ high *fire load* and ultra fast *fire* growth rates (e.g. >1 MW in 75 sec) **(Note 1)**.	Areas involving significant quantities of highly *combustible* and flammable or explosive materials which because of their inherent characteristics constitute a special *fire hazard*, including: bulk plants for flammable liquids or gases, bulk storage warehouses for flammable substances, bulk storage of *foamed plastics.*	4 (The critical factor in this *purpose group* is the rate of *fire* growth.)
INTERMITTENT ACTIVITIES			
IE	*Exitways* on *escape routes.*	*Protected path, safe path.*	1
IA	Spaces for intermittent occupation or providing intermittently used support functions – low *fire load.*	Car parking, garages, carports, enclosed corridors, unstaffed kitchens or laundries, lift shafts, locker rooms, linen rooms, open balconies, *stairways* (within the *open path*), toilets and amenities, and service rooms incorporating machinery or equipment not using solid-fuel, gas or petroleum products as an energy source **(Note 2).**	1
ID	Spaces for intermittent occupation or providing intermittently used support functions – medium *fire load.*	Maintenance workshops and service rooms incorporating machinery or equipment using solid-fuel, gas or petroleum products as an energy source **(Note 2)**.	3

Notes:

1. Refer to NFPA 92B for more information on *fire* growth rates.
2. Service rooms are spaces designed to accommodate any of the following: boiler/plant equipment, furnaces, incinerators, refuse, caretaking/cleaning equipment, airconditioning, heating, plumbing or electrical equipment, pipes, lift/escalator machine rooms, or similar services.

APPENDIX C C/AS1 Table 2.2 Occupant Densities

Table 2.2: Occupant Densities
Paragraphs 2.3.3 and 2.3.7

Activity	Occupant density (Users/m²) (see **Note 1**)
CROWD ACTIVITIES	
Airports – baggage claim	0.5
Airports – concourses	0.1
Airports – waiting areas, check in	0.7
Area without seating or aisles	1.0
Art galleries, museums	0.25
Bar sitting areas	1.0
Bar standing area	2.0
Bleachers, pews or similar bench type seating	2.2 users per linear metre
Classrooms	0.5
Dance floors	1.7
Day care centres	0.25
Dining, beverage and cafeteria spaces	0.8
Exhibition areas, trade fairs	0.7
Fitness centres	0.2
Gymnasia	0.35
Indoor games areas/bowling alleys, etc	0.1
Libraries – stack areas	0.1
Libraries – other areas	0.15
Lobbies and foyers	1.0
Mall areas used for assembly purposes	1.0
Reading or writing rooms and lounges	0.5
Restaurants, dining rooms and lounges	0.9
Shop spaces and pedestrian circulation areas including malls and arcades	0.3
Shop spaces for furniture, floor coverings, large appliances, building supplies and manchester	0.1
Showrooms	0.2
Space with fixed seating	as number of seats (see **Note 2**)
Space with loose seating	1.3
Spaces with loose seating and tables	0.9
Stadia and grandstands	1.8
Stages for theatrical performances	1.3
Standing space	2.6
Swimming pools (water surface area)	0.2
Swimming pool surrounds and seating	0.35
Teaching laboratories	0.2
Vocational training rooms in schools	0.1

Table 2.2: Occupant Densities *(continued)*

Activity	Occupant density (Users/m²) (see **Note 1**)
SLEEPING ACTIVITIES	
Bedrooms Bunkrooms Detention quarters Dormitories, hostels Halls and *wharenui* (**Note 5**) Wards containing more than two beds	as number of beds (see **Note 2**)
WORKING BUSINESS AND STORAGE ACTIVITIES	
Aircraft hangars	0.02
Bulk storage (e.g. solid stacked)	0.01
Commercial laboratories, laundries	0.1
Computer rooms (not used as classrooms for training)	0.04
Factory space in which layout and normal use determines the number of people using it in working hours	as approved (see **Note 3**)
Heavy industry	0.03
Interview rooms	0.2
Kitchens	0.1
Manufacturing and process areas, staffrooms	0.1
Offices and staffrooms	0.1
Personal service facilities	0.2
Reception areas	0.1
Workrooms, workshops	0.2
Warehouse storage (e.g. racks and shelves)	0.03
INTERMITTENT ACTIVITIES	(see **Note 4**)
Boiler rooms, plant rooms, service units and maintenance workshops	0.03
Parking *buildings*, garages	0.02
Exitways, enclosed corridors, lifts (no occupants counted)	0.0
Laundry and house keeping facilities	0.2
Storage	0.02
Toilets and subordinate spaces (no occupants counted)	0.0

Notes:

1. The floor area to be used shall be the total *firecell* floor area including that occupied by internal partitions and *fixtures*. The occupant densities in this table already allow for a proportion of floor area, appropriate to the activity, being occupied by furniture, partitions, *fixtures* and associated equipment.
2. For fixed seating and beds, the number of seats or beds is used instead of an occupant density (users per m²).
3. In such cases, the *occupant load* must be specified when seeking a *building consent*. Future increase in numbers shall be treated as a change of use.
4. Spaces for intermittent activities (*purpose groups* IE, IA, ID), are normally not assessed for *occupant load*. It is assumed that the occupation is temporary and by people who would already have been included in the *occupant load* of another space. The figures given in the table apply where people are specifically employed to perform the functions for which the spaces are provided.
5. For halls and *wharenui*, the maximum *occupant load* is determined by the *fire safety precautions* and the escape capacity. See Paragraphs 3.3.2 h), 3.4.2 e), 6.7.2 and 6.7.9.

APPENDIX D C/AS1 Table 3.1 Number of Escape Routes from a Floor Level

Table 3.1: Number of Escape Routes from a Floor Level
Paragraphs 3.2.2, 3.3.2 b), 3.16.1 and 3.16.5 a)

Occupant load on the floor being considered (Note 1)		Minimum number of escape routes
Purpose groups SC, SD		
Up to	50 beds	2
Over	50	2 plus **(Note 2)**
Purpose groups *SA, SR*		
Up to	100 beds	2
Over	100	2 plus **(Note 3)**
Purpose groups CS, CL, CO, CM, WL, WM, WF, WH, IA, ID		
Up to	500	2 **(Note 4)**
Up to	1000	3
Up to	2000	4
Up to	4000	5
Up to	7000	6
Up to	16,000	8
Over	16,000	8 plus **(Note 5)**

Notes:

1. Guidance on determining *occupant load* is given in Part 2. Special conditions applying to crowd and sleeping *purpose groups* are contained in Paragraph 3.16.
2. Plus 1 for every 100 beds, or part thereof over 50.
3. Plus 1 for every 100 beds, or part thereof over 100.
4. Special cases allowing single *escape routes* are given in Paragraph 3.15.
5. Plus 1 for every 5000, or part thereof increase in *occupant load,* above 16,000.

APPENDIX E C/AS1 Table 3.2 Width of Escape Routes

Table 3.2: Width of Escape Routes
Paragraphs 3.3.2, 3.3.2 h), j) and k), 3.3.6 b), 3.9.12 e)

	Purpose groups		
	CS, CL, CM, SA, SR, WL, WM, WH, WF, IA, ID	SC, SD	CO **(Note 9)**
	Minimum width of individual escape routes (mm)		
Horizontal travel Vertical travel **(Notes 7 and 8)**	850 **(Notes 1, 2, 3, 5)** 1000 **(Note 2)**	1200 1500 **(Note 4)**	1000 1200 **(Note 5)**
	Required total combined width of all escape routes (Note 6) (mm per person)		
Horizontal travel Vertical travel **(Notes 7 and 8)**	7 9	8 10	2 3
Column 1	2	3	4

Notes:

1. The width of an *escape route* within an *exitway*, excluding the entry door (see Paragraph 3.3.2 a)), shall be no less than 1000 mm.
2. Where there is no requirement to provide for *people with disabilities*, and the *occupant load* is less than 50, widths of *escape routes* when an *open path*, may be reduced to 700 mm for horizontal travel, and 850 mm for vertical travel.
3. For gangways between fixed storage in other than public areas, width may be reduced to 530 mm.
4. These widths apply only to *escape routes* from sleeping areas, but the width from column 2 may be used for *escape routes* serving only:
   a) Occupants of non-sleeping areas, or
   b) Sleeping areas where the number of beds is less than 10 and the occupants are active and can be directed by staff, or
   c) Occupants who are active, ambulant and require no assistance to escape.
5. For areas of fixed or loose seating:
   a) *Escape routes* shall comply with the requirements of Paragraphs 3.9.3 and 3.9.4 for aisles and width between rows.
   b) From the termination of an aisle the minimum *escape route* width shall be the greater of the aisle width or the width required by Paragraph 3.3.2.
6. The width calculated on *occupant load* determines any extra width required, but in no case shall the width be less than the minimum for individual *escape routes*.
7. For limitations on width of the *escape route* in *stairways* and where the *escape height* exceeds 34 m, see Paragraphs 3.3.3 and 3.3.4.
8. Ramps with a slope of not more than 1:8 may be regarded as horizontal travel.
9. The widths given in column 4 apply only to *escape routes* wholly in the open air. Any enclosed part of the *escape route* shall be the width determined for CL using column 2 and that width shall not be reduced even if the *escape route* subsequently passes to the open air.

APPENDIX F C/AS1 Table 3.3 Length of Open Paths and Protected Paths

Table 3.3: Lengths of Open Paths and Protected Paths
Paragraphs 1.3.4, 3.4.1 a), 3.4.2 b), d) and e), 3.4.4, 3.4.6, 3.4.8, 3.5.1, 3.5.2, 3.5.3, 3.5.6, 3.8.1, 3.9.7, 3.11.7, 3.15.1 b) and c), 3.15.5 c), 6.8.2 and Figures 3.7, 3.15 and 3.21

Type of path	**Purpose groups**				
	SC, SD **(Note 4)**	WF	CS, CL, CM, SA	WL, WM, WH, SR, SH	CO, IA, ID
	Maximum length (m)				
Dead end open path	18	12	18	24	36
Total open path (Note 5)	45	30	45	60	90
Protected path	45	30	45	60	90
Column 1	2	3	4	5	6

Notes:

1. Where the *occupant load* exceeds 50, there shall be two or more *escape routes* from any space.
2. In accordance with Paragraphs 3.5 and 3.11.7 *open path* lengths and horizontal *safe path* lengths (but not protected paths), may be increased by:

	SA, SR, SH	CS, CL, CM, WL, WM, WH, IA, ID
where heat detectors are installed	10%	20%
where sprinklers are installed	50%	100%
where smoke detectors Types 4, 5 or 7 are installed	50%	100%

3. Paragraph 3.5.6 gives the circumstances where permitted increases, in the lengths of *dead end* and total *open path* may be combined.
4. Because *purpose groups* SC and SD are required by Table 4.1 always to have sprinklers and smoke detectors, no increases in accordance with Paragraph 3.5 are permitted for those *purpose groups*.
5. Allowed only if there is more than one *escape route*, but shall include any initial *dead end* length.

APPENDIX G C/AS1 Table 4.1 Fire Safety Precautions

Table 4.1: Fire Safety Precautions
Key to table references

Part 3	Paragraphs 3.1.5, 3.13.1 and 3.19.2
Part 4	Paragraphs 4.3, 4.3.1, 4.3.3, 4.4.1, 4.5.2, 4.5.3, 4.5.4, 4.5.7, 4.5.8, 4.5.9, 4.5.10, 4.5.13, 4.5.14, 4.5.15, 4.5.19
Part 5	Paragraphs 5.5.1, 5.6.6, 5.6.8, 5.9.4 (c)
Part 6	Paragraphs 6.2.1, 6.4.1, 6.7.1, 6.8.1, 6.8.5, 6.8.6, 6.10.1, 6.11.1, 6.15.1, 6.19.9, 6.21.2, 6.23.1 (d), 6.23.2, 6.23.3
Part 8	Paragraphs 8.2.1, 8.2.2, 8.2.3
Appendix A	Paragraphs A1.1.1 and A1.1.2

Fire safety precautions

Type	Description
1	Domestic smoke alarm system.
2	Manual fire alarm system.
3	Automatic fire alarm system with heat detectors and manual call points.
4	Automatic fire alarm system with smoke detectors and manual call points.
5	Automatic fire alarm system with modified smoke/heat detection and manual call points.
6	Automatic fire sprinkler system with manual call points.
7	Automatic fire sprinkler system with smoke detectors and manual call points.
8	Voice communication system.
9	Smoke control in air handling system.
10	Natural smoke venting.
11	Mechanical smoke extract.
12	No Type 12 currently specified.
13	Pressurisation of safe paths.
14	Fire hose reels.
15	Fire Service lift control.
16	Visibility in escape routes.
17	Emergency electrical power supply.
18	Fire hydrant system.
19	Refuge areas.
20.	Fire systems centre.

Special applications

a Not required where:

i) the *escape routes* serve an *occupant load* of no more than 50 in *purpose groups* CS (excluding *early childhood centres*), CM, WL, WM, WH and WF, or

ii) the *escape routes* are for *purpose group* SA and serve no more than 10 beds, (or 20 beds for trampers huts, see Paragraph 6.20.6), or

iii) exit doors from *purpose group* SA and SR *firecells* open directly onto a *safe place* or an external *safe path* (see Paragraph 3.14).

b Where only a single *escape route* is available, no less than a Type 4 alarm is required. See Paragraph 3.15.3 for situations where sprinklers are required.

c Required where Fire Service hose run distance, from the Fire Service vehicular access (see Paragraph 8.1.1) to any point on any floor, is greater than 75 m.

e The smoke detection element is Type 5 within *firecells* containing sleeping accommodation. (See Appendix A for description of Type 5.)

f A direct connection to the Fire Service is not required provided a telephone is installed and freely available at all times to enable 111 calls to be made.

Note:

The numbered references are more fully explained in Appendix A. Throughout Table 4.1 dark shading identifies where sprinklers are required.

Table 4.1/1: Fire safety precautions for active purpose group firecells Occupant load 100

<table>
<tr><th rowspan="2">Purpose group</th><th rowspan="2">FHC</th><th colspan="12">Escape height</th></tr>
<tr><th>0 m (or single floor)</th><th colspan="2"><4 m (or two floors)</th><th colspan="2">4 m to <10 m</th><th colspan="2">10 m to <25 m</th><th>25 m to <34 m</th><th>34 m to <46 m</th><th>46 m to <58 m</th><th>over 58 m</th></tr>
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Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4.
6. **Visibility in escape routes:** is specified in NZBC Clause F6.

Table 4.1/2: Fire safety precautions for active purpose group firecells Occupant load 101 to 500

Purpose group	FHC	Escape height: 0 m (or single floor)	<4 m (or two floors)		4 m to <10 m		10 m to <25 m		25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL	1	F0	F45		F45		F45		F30	F45	F45	F60
(Note 7)	2	F0	F60		F60		F60		F45	F45	F60	F90
	3	F0	F60		F60		F90		F45	F60	F60	F90
		3f 16 18c	3f 16 18c		3b 9 16 18c		4 9 16 18		6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM	2	F0	F60		F60		F60		F45	F45	F60	F90
(Note 5)	4	F0		F30		F30		F45	F45	F60	F60	F90
		3f 16 18c	3f 16 18c	6 16 18c	3b 9 16 18c	6 9 16 18c	3b 9 15 16 18	6 9 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL	1	F0	F45		F45		F45		F30	F45	F45	F60
WM	2	F0	F60		F60		F60		F45	F45	F60	F90
WH	3	F0	F60		F60		F90		F45	F60	F60	F90
(Note 5)	4	F0		F30		F30		F45	F45	F60	F60	F90
		3f 16 18c	3f 16 18c	6 16 18c	3b 16 18c	6 16 18c	3b 15 16 18	6 15 16 18	6 15 16 18	6 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	4	F0	F30		F30		F45		F45	F60	F60	F90
		3f 16 18c	6 16 18c		6 16 18c		6 15 16 18		6 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column		1	2		3		4		5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4.
6. **Visibility in escape routes:** is specified in NZBC Clause F6.
7. **CL:** For *firecells*, which are not cinemas or *theatres*, with *escape height* less than 4.0 m and *occupant load* not greater than 250, Type 2f is a permitted alternative to Type 3f.

Table 4.1/3: Fire safety precautions for active purpose group firecells
Occupant load 501 to 1000

<table>
<tr><th></th><th></th><th colspan="10">Escape height</th></tr>
<tr><th>Purpose group</th><th>FHC</th><th>0 m (or single floor)</th><th colspan="2"><4 m (or two floors)</th><th colspan="2">4 m to <10 m</th><th>10 m to <25 m</th><th>25 m to <34 m</th><th>34 m to <46 m</th><th>46 m to <58 m</th><th>over 58 m</th></tr>
<tr><td>CL</td><td>1</td><td>F0</td><td colspan="2">F45</td><td colspan="2">F45</td><td>F30</td><td>F30</td><td>F45</td><td>F45</td><td>F60</td></tr>
<tr><td></td><td>2</td><td>F0</td><td colspan="2">F60</td><td colspan="2">F60</td><td>F30</td><td>F45</td><td>F45</td><td>F60</td><td>F90</td></tr>
<tr><td></td><td>3</td><td>F0</td><td colspan="2">F60</td><td colspan="2">F60</td><td>F45</td><td>F45</td><td>F60</td><td>F60</td><td>F90</td></tr>
<tr><td></td><td></td><td>4
16
18c</td><td colspan="2">4
16
18c</td><td colspan="2">4
9
16
18c</td><td>7
9
16
18</td><td>7
9
13
15
16
18</td><td>7
9
13
15
16
18</td><td>7
9
13
15
16
18</td><td>7
9
13
15
16
17
18
19
20</td></tr>
<tr><td>CM</td><td>2</td><td>F0</td><td>F60</td><td></td><td>F60</td><td></td><td>F30</td><td>F45</td><td>F45</td><td>F60</td><td>F90</td></tr>
<tr><td>(Note 5)</td><td>4</td><td>F0</td><td></td><td>F30</td><td></td><td>F30</td><td>F45</td><td>F45</td><td>F60</td><td>F60</td><td>F90</td></tr>
<tr><td></td><td></td><td>4
16
18c</td><td>4
16
18c</td><td>6
16
18c</td><td>4
9
16
18c</td><td>6
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16
18c</td><td>7
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18</td><td>7
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18
20</td><td>7
9
13
15
16
18
20</td><td>7
9
13
15
16
17
18
19
20</td></tr>
<tr><td>WL</td><td>1</td><td>F0</td><td>F45</td><td></td><td>F45</td><td></td><td>F30</td><td>F30</td><td>F45</td><td>F45</td><td>F60</td></tr>
<tr><td>WM</td><td>2</td><td>F0</td><td>F60</td><td></td><td>F60</td><td></td><td>F30</td><td>F45</td><td>F45</td><td>F60</td><td>F90</td></tr>
<tr><td>WH</td><td>3</td><td>F0</td><td>F60</td><td></td><td>F60</td><td></td><td>F45</td><td>F45</td><td>F60</td><td>F60</td><td>F90</td></tr>
<tr><td>(Note 5)</td><td>4</td><td>F0</td><td></td><td>F30</td><td></td><td>F30</td><td>F45</td><td>F45</td><td>F60</td><td>F60</td><td>F90</td></tr>
<tr><td></td><td></td><td>4
16
18c</td><td>4
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18c</td><td>6
16
18c</td><td>4
16
18c</td><td>6
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18c</td><td>7
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18</td><td>7
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16
18</td><td>7
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13
15
16
18
19
20</td></tr>
<tr><td>WF</td><td>4</td><td>F0</td><td colspan="2">F30</td><td colspan="2">F30</td><td>F45</td><td>F45</td><td>F60</td><td>F60</td><td>F90</td></tr>
<tr><td></td><td></td><td>4
16
18c</td><td colspan="2">6
16
18c</td><td colspan="2">6
16
18c</td><td>7
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16
18</td><td>7
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18</td><td>7
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18
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20</td></tr>
<tr><td>Column</td><td></td><td>1</td><td colspan="2">2</td><td colspan="2">3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
</table>

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* an *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4.
6. **Visibility in escape routes:** is specified in NZBC Clause F6.

Table 4.1/4: Fire safety precautions for active purpose group firecells Occupant load over 1000

Purpose group	FHC	Escape height: 0 m (or single floor)	<4 m (or two floors)	4 m to <10 m	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL	1	F0	F30	F30	F30	F30	F45	F45	F60
	2	F0	F30	F30	F30	F45	F60	F60	F90
	3	F0	F30	F30	F45	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 9 16 18c	7 9 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM	2	F0	F30	F30	F30	F45	F45	F60	F90
(Note 5)	4	F0	F30	F30	F45	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 9 16 18c	7 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL	1	F0	F30	F30	F30	F30	F45	F45	F60
WM	2	F0	F30	F30	F30	F45	F45	F60	F90
WH	3	F0	F30	F30	F30	F45	F60	F60	F90
(Note 5)	4	F0	F30	F30	F30	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 16 18c	7 15 16 18	7 15 16 18	7 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	4	F0	F30	F30	F45	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 16 18c	7 15 16 18	7 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column		1	2	3	4	5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4.
6. **Visibility in escape routes:** is specified in NZBC Clause F6.

Table 4.1/5: Fire safety precautions for sleeping purpose group firecells Occupant load 40 maximum

Purpose Group	FHC	Escape height: 0 m (or single floor)	<4 m (or two floors)	4 m to <10 m	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
SC **SD**	1	**F0**	**F30**	**F30**	**F30**	**F30**	**F45**	**F45**	**F60**
		7 16 18c	7 16 18c	7 16 18c	7 9 15 16 18	7 8 9 13 15 16 18 20	7 8 9 13 15 16 18 20	7 8 9 13 15 16 18 20	7 8 9 13 15 16 17 18 19 20
SA (Note 5)	1	**F0**	**F45**	**F45**	**F45**	**F30**	**F45**	**F45**	**F60**
		5af 16 18c	5f 16 18c	5 14 16 18c	5 14 15 16 18	7e 8 9 15 16 18	7e 8 9 13 15 16 18 20	7e 8 9 13 15 16 18 20	7e 8 9 13 15 16 17 18 20
SR (Note 7)	1	**F0**	**F45**	**F45**	**F45**	**F30**	**F45**	**F45**	**F60**
		1 16	1 2af 16	1 2f 16	5 14 16 18	7e 15 16 18	7e 15 16 18	7e 15 16 18 20	7e 13 15 16 18 20
Column		1	2	3	4	5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** *Purpose group* SA may have an *occupant load* up to 160 beds in *firecells* with a Type 7 alarm (see Paragraph 6.7.2).
6. **Occupant load in SC and SD firecells:** The *occupant load* in a *group sleeping area firecell* is limited to 12 or 20 beds and in a *suite* to six beds (see Paragraphs 6.6.3 to 6.6.5). For *firecells* (such as an operating theatre) required to remain occupied during a *fire*, see Paragraphs 5.6.8 and 5.6.9.
7. **SR household units:** See Paragraph 6.8.6 which describes where *household units* containing upper floors may be treated as single floor *firecells*.
8. **Visibility in escape routes:** is specified in NZBC Clause F6.

APPENDIX H BRANZFIRE Input File

1. Nightclub - Basement Bar Fire

```
basement bar fire - no sprinkler with heat detector
====================================================================
Description of Rooms
====================================================================
Room  1  : Bar
       Room Length (m) =                          13.00
       Room Width (m) =                           7.00
       Maximum Room Height (m) =                   2.50
       Minimum Room Height (m) =                   2.50
       Floor Elevation (m) =                      0.500
       Room  1  has a flat ceiling.

       Wall Surface is plasterboard
       Wall Density (kg/m3) =                      810.0
       Wall Conductivity (W/m.K) =                  0.160
       Wall Emissivity =                          0.88
       Wall Thickness (mm) =                       16.0

       Wall Substrate is concrete
       Wall Substrate Density (kg/m3) =              2300.0
       Wall Substrate Conductivity (W/m.K) =          1.200
       Wall Substrate Thickness (mm) =               100.0

       Ceiling Surface is concrete
       Ceiling Density (kg/m3) =                    2300.0
       Ceiling Conductivity (W/m.K) =                1.200
       Ceiling Emissivity =                        0.50
       Ceiling Thickness (mm) =                     100.0

       Floor Surface is concrete
       Floor Density (kg/m3) =                      2300.0
       Floor Conductivity (W/m.K) =                  1.200
       Floor Emissivity =                          0.50
       Floor Thickness = (mm)                       100.0

Room  2  : Foyer
       Room Length (m) =                          11.50
       Room Width (m) =                           3.20
       Maximum Room Height (m) =                   3.00
       Minimum Room Height (m) =                   3.00
       Floor Elevation (m) =                      0.000
       Room  2  has a flat ceiling.

       Wall Surface is plasterboard
       Wall Density (kg/m3) =                      810.0
       Wall Conductivity (W/m.K) =                  0.160
       Wall Emissivity =                          0.88
       Wall Thickness (mm) =                       16.0

       Wall Substrate is concrete
       Wall Substrate Density (kg/m3) =              2300.0
       Wall Substrate Conductivity (W/m.K) =          1.200
       Wall Substrate Thickness (mm) =               100.0

       Ceiling Surface is concrete
       Ceiling Density (kg/m3) =                    2300.0
       Ceiling Conductivity (W/m.K) =                1.200
       Ceiling Emissivity =                        0.50
       Ceiling Thickness (mm) =                     100.0

       Floor Surface is concrete
       Floor Density (kg/m3) =                      2300.0
       Floor Conductivity (W/m.K) =                  1.200
       Floor Emissivity =                          0.50
       Floor Thickness = (mm)                       100.0

Room  3  : Corridor
       Room Length (m) =                          8.00
       Room Width (m) =                           1.50
```

```
        Maximum Room Height (m) =                   2.50
        Minimum Room Height (m) =                   2.50
        Floor Elevation (m) =                       0.500
        Room  3  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                      810.0
        Wall Conductivity (W/m.K) =                  0.160
        Wall Emissivity =                           0.88
        Wall Thickness (mm) =                       16.0

        Wall Substrate is concrete
        Wall Substrate Density (kg/m3) =              2300.0
        Wall Substrate Conductivity (W/m.K) =          1.200
        Wall Substrate Thickness (mm) =               100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                   2300.0
        Ceiling Conductivity (W/m.K) =               1.200
        Ceiling Emissivity =                        0.50
        Ceiling Thickness (mm) =                    100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                     2300.0
        Floor Conductivity (W/m.K) =                 1.200
        Floor Emissivity =                          0.50
        Floor Thickness = (mm)                      100.0

Room  4  : Stair1
        Room Length (m) =                           2.60
        Room Width (m) =                            1.67
        Maximum Room Height (m) =                   5.50
        Minimum Room Height (m) =                   5.50
        Floor Elevation (m) =                       0.500
        Room  4  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                      810.0
        Wall Conductivity (W/m.K) =                  0.160
        Wall Emissivity =                           0.88
        Wall Thickness (mm) =                       16.0

        Wall Substrate is concrete
        Wall Substrate Density (kg/m3) =              2300.0
        Wall Substrate Conductivity (W/m.K) =          1.200
        Wall Substrate Thickness (mm) =               100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                   2300.0
        Ceiling Conductivity (W/m.K) =               1.200
        Ceiling Emissivity =                        0.50
        Ceiling Thickness (mm) =                    100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                     2300.0
        Floor Conductivity (W/m.K) =                 1.200
        Floor Emissivity =                          0.50
        Floor Thickness = (mm)                      100.0

Room  5  : Stair2
        Room Length (m) =                           5.10
        Room Width (m) =                            1.67
        Maximum Room Height (m) =                   17.50
        Minimum Room Height (m) =                   17.50
        Floor Elevation (m) =                       0.500
        Room  5  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                      810.0
        Wall Conductivity (W/m.K) =                  0.160
        Wall Emissivity =                           0.88
        Wall Thickness (mm) =                       16.0

        Wall Substrate is concrete
```

```
        Wall Substrate Density (kg/m3) =               2300.0
        Wall Substrate Conductivity (W/m.K) =           1.200
        Wall Substrate Thickness (mm) =                100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                     2300.0
        Ceiling Conductivity (W/m.K) =                 1.200
        Ceiling Emissivity =                          0.50
        Ceiling Thickness (mm) =                       100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                       2300.0
        Floor Conductivity (W/m.K) =                   1.200
        Floor Emissivity =                            0.50
        Floor Thickness = (mm)                         100.0
====================================================================
Wall Vents
====================================================================
From room  1  to  2 , Vent No 1
                Vent Width (m) =                     0.860
                Vent Height (m) =                    2.000
                Vent Sill Height (m) =                0.000
                Vent Soffit Height (m) =              2.000
                Opening Time (sec) =                 0
                Closing Time (sec) =                 0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  1  to  4 , Vent No 1
                Vent Width (m) =                     0.860
                Vent Height (m) =                    2.000
                Vent Sill Height (m) =                0.000
                Vent Soffit Height (m) =              2.000
                Opening Time (sec) =                 0
                Closing Time (sec) =                 0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  2  to  3 , Vent No 1
                Vent Width (m) =                     0.860
                Vent Height (m) =                    2.000
                Vent Sill Height (m) =                0.500
                Vent Soffit Height (m) =              2.500
                Opening Time (sec) =                 0
                Closing Time (sec) =                 0
                This vent can automatically open with the following trigger(s)
                Heat Detection in Room 1
From room  2  to  4 , Vent No 1
                Vent Width (m) =                     0.860
                Vent Height (m) =                    2.500
                Vent Sill Height (m) =                0.500
                Vent Soffit Height (m) =              3.000
                Opening Time (sec) =                 0
                Closing Time (sec) =                 0
                This vent can automatically open with the following trigger(s)
                Heat Detection in Room 1

From room  3  to  5 , Vent No 1
                Vent Width (m) =                     1.700
                Vent Height (m) =                    2.500
                Vent Sill Height (m) =                0.000
                Vent Soffit Height (m) =              2.500
                Opening Time (sec) =                 0
                Closing Time (sec) =                 0
====================================================================
Ceiling/Floor Vents
====================================================================
====================================================================
Ambient Conditions
====================================================================
Interior Temp (C) =                                  21.0
Exterior Temp (C) =                                  20.0
Relative Humidity (%) =                               65
```

```
===================================================================
Tenability Parameters
===================================================================
Monitoring Height for Visibility and FED (m) =          2.00
Occupant Activity Level =                           Light
Visibility calculations assume:                      illuminated signs
FED Start Time (sec)                               0
FED End Time (sec)                                 10000
===================================================================
Sprinkler / Detector Parameters
===================================================================
Heat detector installed in Room                      1
       Response Time Index (m.s)^1/2 =               30.0
       Radial Distance (m) =                       4.2
       Actuation Temperature (C) =                  57.0
       Distance below ceiling (mm) =                20
       Ceiling Jet model used is NIST JET.
===================================================================
Mechanical Ventilation (to/from outside)
===================================================================
Mechanical Ventilation not installed in Room 1
Mechanical Ventilation not installed in Room 2
Mechanical Ventilation not installed in Room 3
Mechanical Ventilation not installed in Room 4
Mechanical Ventilation not installed in Room 5
===================================================================
Description of the Fire
===================================================================
Radiant Loss Fraction =                             0.35
CO Yield pre-flashover(g/g) =                        0.040
CO Yield post-flashover(g/g) =                       0.400
Soot Yield pre-flashover(g/g) =                      0.070
Soot Yield post-flashover(g/g) =                     0.140
Smoke Emission Coefficient (1/m) =                   1.20
Characteristic Mass Loss per Unit Area (kg/s.m2) =       0.011
Air Entrainment in Plume uses McCaffrey (default)

Burning Object No 1
           Located in Room                         1
           Energy Yield (kJ/g) =                    20.0
           CO2 Yield (kg/kg fuel) =                 1.920
           HCN Yield (kg/kg fuel) =                 0.000
           Fire Height (m) =                       0.400
           Fire Location =                         Centre

           Time (sec)            Heat Release (kW)
            0                   0
            30                  42
            60                  169
            90                  381
            120                 677
            150                 1058
            180                 1523
            210                 2073
            240                 2707
            241                 2730
            242                 2753
            243                 2775
            244                 2798
            245                 2821
            246                 2844
            247                 2867
            248                 2891
            249                 2914
            250                 2938
            270                 3376
            1800                3376 (Ventilation Controlled)
===================================================================
Postflashover Inputs
===================================================================
Postflashover model is OFF.
```

2. Hospital - Ground Floor Cafeteria Fire

```
BRANZFIRE Multi-Compartment Fire Model (Ver 2010.5)

Cafe fire - Hospital
====================================================================
Description of Rooms
====================================================================
Room  1  : Cafeteria
       Room Length (m) =                          20.00
       Room Width (m) =                           14.00
       Maximum Room Height (m) =                   2.50
       Minimum Room Height (m) =                   2.50
       Floor Elevation (m) =                      0.000
       Room  1  has a flat ceiling.

       Wall Surface is plasterboard
       Wall Density (kg/m3) =                     810.0
       Wall Conductivity (W/m.K) =                 0.160
       Wall Emissivity =                          0.88
       Wall Thickness (mm) =                      16.0

       Wall Substrate is concrete
       Wall Substrate Density (kg/m3) =              2300.0
       Wall Substrate Conductivity (W/m.K) =          1.200
       Wall Substrate Thickness (mm) =               100.0

       Ceiling Surface is concrete
       Ceiling Density (kg/m3) =                  2300.0
       Ceiling Conductivity (W/m.K) =              1.200
       Ceiling Emissivity =                       0.50
       Ceiling Thickness (mm) =                   100.0

       Floor Surface is concrete
       Floor Density (kg/m3) =                    2300.0
       Floor Conductivity (W/m.K) =                1.200
       Floor Emissivity =                         0.50
       Floor Thickness = (mm)                     100.0

Room  2  : Physiotherapy
       Room Length (m) =                          26.50
       Room Width (m) =                           23.60
       Maximum Room Height (m) =                   2.50
       Minimum Room Height (m) =                   2.50
       Floor Elevation (m) =                      0.000
       Room  2  has a flat ceiling.

       Wall Surface is plasterboard
       Wall Density (kg/m3) =                     810.0
       Wall Conductivity (W/m.K) =                 0.160
       Wall Emissivity =                          0.88
       Wall Thickness (mm) =                      16.0

       Wall Substrate is concrete
       Wall Substrate Density (kg/m3) =              2300.0
       Wall Substrate Conductivity (W/m.K) =          1.200
       Wall Substrate Thickness (mm) =               100.0

       Ceiling Surface is concrete
       Ceiling Density (kg/m3) =                  2300.0
       Ceiling Conductivity (W/m.K) =              1.200
       Ceiling Emissivity =                       0.50
       Ceiling Thickness (mm) =                   100.0

       Floor Surface is concrete
       Floor Density (kg/m3) =                    2300.0
       Floor Conductivity (W/m.K) =                1.200
       Floor Emissivity =                         0.50
       Floor Thickness = (mm)                     100.0

Room  3  : Corridor 1
       Room Length (m) =                          54.00
       Room Width (m) =                           3.60
```

```
        Maximum Room Height (m) =                    2.50
        Minimum Room Height (m) =                    2.50
        Floor Elevation (m) =                       0.000
        Room  3  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                      810.0
        Wall Conductivity (W/m.K) =                  0.160
        Wall Emissivity =                          0.88
        Wall Thickness (mm) =                       16.0

        Wall Substrate is concrete
        Wall Substrate Density (kg/m3) =              2300.0
        Wall Substrate Conductivity (W/m.K) =          1.200
        Wall Substrate Thickness (mm) =               100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                    2300.0
        Ceiling Conductivity (W/m.K) =                1.200
        Ceiling Emissivity =                        0.50
        Ceiling Thickness (mm) =                     100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                      2300.0
        Floor Conductivity (W/m.K) =                  1.200
        Floor Emissivity =                          0.50
        Floor Thickness = (mm)                       100.0

Room  4  : Corridor 2
        Room Length (m) =                          74.00
        Room Width (m) =                           3.40
        Maximum Room Height (m) =                    2.50
        Minimum Room Height (m) =                    2.50
        Floor Elevation (m) =                       0.000
        Room  4  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                      810.0
        Wall Conductivity (W/m.K) =                  0.160
        Wall Emissivity =                          0.88
        Wall Thickness (mm) =                       16.0

        Wall Substrate is concrete
        Wall Substrate Density (kg/m3) =              2300.0
        Wall Substrate Conductivity (W/m.K) =          1.200
        Wall Substrate Thickness (mm) =               100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                    2300.0
        Ceiling Conductivity (W/m.K) =                1.200
        Ceiling Emissivity =                        0.50
        Ceiling Thickness (mm) =                     100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                      2300.0
        Floor Conductivity (W/m.K) =                  1.200
        Floor Emissivity =                          0.50
        Floor Thickness = (mm)                       100.0

Room  5  : Corridor 3
        Room Length (m) =                          54.00
        Room Width (m) =                           4.20
        Maximum Room Height (m) =                    2.50
        Minimum Room Height (m) =                    2.50
        Floor Elevation (m) =                       0.000
        Room  5  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                      810.0
        Wall Conductivity (W/m.K) =                  0.160
        Wall Emissivity =                          0.88
        Wall Thickness (mm) =                       16.0

        Wall Substrate is concrete
```

```
        Wall Substrate Density (kg/m3) =              2300.0
        Wall Substrate Conductivity (W/m.K) =          1.200
        Wall Substrate Thickness (mm) =               100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                     2300.0
        Ceiling Conductivity (W/m.K) =                 1.200
        Ceiling Emissivity =                         0.50
        Ceiling Thickness (mm) =                      100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                       2300.0
        Floor Conductivity (W/m.K) =                   1.200
        Floor Emissivity =                           0.50
        Floor Thickness = (mm)                        100.0

Room  6  : Foyer
        Room Length (m) =                            26.00
        Room Width (m) =                             9.20
        Maximum Room Height (m) =                     2.50
        Minimum Room Height (m) =                     2.50
        Floor Elevation (m) =                         0.000
        Room  6  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                        810.0
        Wall Conductivity (W/m.K) =                    0.160
        Wall Emissivity =                            0.88
        Wall Thickness (mm) =                         16.0

        Wall Substrate is concrete
        Wall Substrate Density (kg/m3) =              2300.0
        Wall Substrate Conductivity (W/m.K) =          1.200
        Wall Substrate Thickness (mm) =               100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                     2300.0
        Ceiling Conductivity (W/m.K) =                 1.200
        Ceiling Emissivity =                         0.50
        Ceiling Thickness (mm) =                      100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                       2300.0
        Floor Conductivity (W/m.K) =                   1.200
        Floor Emissivity =                           0.50
        Floor Thickness = (mm)                        100.0

Room  7  : Stair 1
        Room Length (m) =                            7.00
        Room Width (m) =                             3.40
        Maximum Room Height (m) =                     10.00
        Minimum Room Height (m) =                     10.00
        Floor Elevation (m) =                         0.000
        Room  7  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                        810.0
        Wall Conductivity (W/m.K) =                    0.160
        Wall Emissivity =                            0.88
        Wall Thickness (mm) =                         16.0

        Wall Substrate is concrete
        Wall Substrate Density (kg/m3) =              2300.0
        Wall Substrate Conductivity (W/m.K) =          1.200
        Wall Substrate Thickness (mm) =               100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                     2300.0
        Ceiling Conductivity (W/m.K) =                 1.200
        Ceiling Emissivity =                         0.50
        Ceiling Thickness (mm) =                      100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                       2300.0
```

```
        Floor Conductivity (W/m.K) =                   1.200
        Floor Emissivity =                            0.50
        Floor Thickness = (mm)                         100.0

Room  8  : Stair 2
        Room Length (m) =                             7.00
        Room Width (m) =                              3.40
        Maximum Room Height (m) =                      10.00
        Minimum Room Height (m) =                      10.00
        Floor Elevation (m) =                         0.000
        Room  8  has a flat ceiling.

        Wall Surface is plasterboard
        Wall Density (kg/m3) =                         810.0
        Wall Conductivity (W/m.K) =                     0.160
        Wall Emissivity =                             0.88
        Wall Thickness (mm) =                         16.0

        Wall Substrate is concrete
        Wall Substrate Density (kg/m3) =                2300.0
        Wall Substrate Conductivity (W/m.K) =           1.200
        Wall Substrate Thickness (mm) =                100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                      2300.0
        Ceiling Conductivity (W/m.K) =                  1.200
        Ceiling Emissivity =                          0.50
        Ceiling Thickness (mm) =                       100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                        2300.0
        Floor Conductivity (W/m.K) =                   1.200
        Floor Emissivity =                            0.50
        Floor Thickness = (mm)                         100.0

====================================================================
Wall Vents
====================================================================
From room  1  to  3 , Vent No 1
                Vent Width (m) =                    0.020
                Vent Height (m) =                   2.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to  4 , Vent No 1
                Vent Width (m) =                    0.860
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to outside, Vent No 1
                Vent Width (m) =                    0.430
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0
                This vent can automatically open with the following trigger(s)
                Sprinkler in Room 1

From room  1  to outside, Vent No 2
                Vent Width (m) =                    0.010
                Vent Height (m) =                   2.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  2  to  4 , Vent No 1
                Vent Width (m) =                    0.860
```

```
                 Vent Height (m) =                   2.000
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.000
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0

From room  2  to  6 , Vent No 1
                 Vent Width (m) =                    0.024
                 Vent Height (m) =                   2.500
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.500
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0

From room  2  to outside, Vent No 1
                 Vent Width (m) =                    0.025
                 Vent Height (m) =                   2.500
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.500
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0

From room  3  to  4 , Vent No 1
                 Vent Width (m) =                    3.600
                 Vent Height (m) =                   2.500
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.500
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0

From room  3  to  5 , Vent No 1
                 Vent Width (m) =                    4.200
                 Vent Height (m) =                   2.500
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.500
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0

From room  3  to outside, Vent No 1
                 Vent Width (m) =                    0.860
                 Vent Height (m) =                   2.000
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.000
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0
                 This vent can automatically open with the following trigger(s)
                 Sprinkler in Room 1

From room  4  to  6 , Vent No 1
                 Vent Width (m) =                    3.400
                 Vent Height (m) =                   2.500
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.500
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0

From room  4  to  7 , Vent No 1
                 Vent Width (m) =                    0.440
                 Vent Height (m) =                   2.000
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.000
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0
                 This vent can automatically open with the following trigger(s)
                 Sprinkler in Room 1

From room  4  to  8 , Vent No 1
                 Vent Width (m) =                    0.440
                 Vent Height (m) =                   2.000
                 Vent Sill Height (m) =               0.000
                 Vent Soffit Height (m) =             2.000
                 Opening Time (sec) =                0
                 Closing Time (sec) =                0
                 This vent can automatically open with the following trigger(s)
```

```
                Sprinkler in Room 1

From room  5  to  6 , Vent No 1
                Vent Width (m) =                    4.200
                Vent Height (m) =                   2.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  6  to outside, Vent No 1
                Vent Width (m) =                    0.860
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0
                This vent can automatically open with the following trigger(s)
                Sprinkler in Room 1

From room  7  to outside, Vent No 1
                Vent Width (m) =                    0.430
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0
                This vent can automatically open with the following trigger(s)
                Sprinkler in Room 1

From room  7  to outside, Vent No 2
                Vent Width (m) =                    0.007
                Vent Height (m) =                   10.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             10.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  8  to outside, Vent No 1
                Vent Width (m) =                    0.430
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0
                This vent can automatically open with the following trigger(s)
                Sprinkler in Room 1

From room  8  to outside, Vent No 2
                Vent Width (m) =                    0.003
                Vent Height (m) =                   10.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             10.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

====================================================================
Ceiling/Floor Vents
====================================================================
====================================================================
Ambient Conditions
====================================================================
Interior Temp (C) =                                 21.0
Exterior Temp (C) =                                 20.0
Relative Humidity (%) =                              65
====================================================================
Tenability Parameters
====================================================================
Monitoring Height for Visibility and FED (m) =          2.00
Occupant Activity Level =                            Light
Visibility calculations assume:                        illuminated signs
FED Start Time (sec)                                0
FED End Time (sec)                                  10000
```

```
====================================================================
Sprinkler / Detector Parameters
====================================================================
Sprinkler installed in Room                          1
       Sprinkler control is simulated.
       Response Time Index (m.s)^1/2 =               95.0
       Sprinkler C-Factor (m.s)^1/2 =                0.40
       Radial Distance (m) =                        2.80
       Actuation Temperature (C) =                   68.0
       Water Spray Density (mm/min) =                0.0
       Distance below ceiling (mm) =                 20
       Ceiling Jet model used is NIST JET.
====================================================================
Mechanical Ventilation (to/from outside)
====================================================================
Mechanical Ventilation not installed in Room 1
Mechanical Ventilation not installed in Room 2
Mechanical Ventilation not installed in Room 3
Mechanical Ventilation not installed in Room 4
Mechanical Ventilation not installed in Room 5
Mechanical Ventilation not installed in Room 6
Mechanical Ventilation not installed in Room 7
Mechanical Ventilation not installed in Room 8
====================================================================
Description of the Fire
====================================================================
Radiant Loss Fraction =                              0.35
CO Yield pre-flashover(g/g) =                         0.040
CO Yield post-flashover(g/g) =                        0.400
Soot Yield pre-flashover(g/g) =                       0.070
Soot Yield post-flashover(g/g) =                      0.140
Smoke Emission Coefficient (1/m) =                    1.20
Characteristic Mass Loss per Unit Area (kg/s.m2) =       0.011
Air Entrainment in Plume uses McCaffrey (default)

Burning Object No 1

           Located in Room                      1
           Energy Yield (kJ/g) =                 20.0
           CO2 Yield (kg/kg fuel) =              1.920
           HCN Yield (kg/kg fuel) =              0.000
           Fire Height (m) =                    0.400
           Fire Location =                      Centre

           Time (sec)           Heat Release (kW)
            0                  0
            30                 42
            60                 169
            90                 381
            120                677
            150                1058
            180                1523
            210                2073
            240                2707
            270                3426
            300                4230
            330                5118
            360                6091
            390                7149
            420                8291
            450                9518
            480                10829
            652                20000
           1800                20000

====================================================================
Postflashover Inputs
====================================================================
Postflashover model is OFF.
```

3. Shopping Mall – Medium Shop Fire

```
BRANZFIRE Multi-Compartment Fire Model (Ver 2010.5)

Medium shop fire - shopping mall
====================================================================
Description of Rooms
====================================================================
Room  1  : Atrium
       Room Length (m) =                           30.00
       Room Width (m) =                            25.00
       Maximum Room Height (m) =                    12.00
       Minimum Room Height (m) =                    12.00
       Floor Elevation (m) =                        0.000
       Room  1  has a flat ceiling.

       Wall Surface is concrete
       Wall Density (kg/m3) =                        2300.0
       Wall Conductivity (W/m.K) =                    1.200
       Wall Emissivity =                            0.50
       Wall Thickness (mm) =                         100.0

       Ceiling Surface is concrete
       Ceiling Density (kg/m3) =                     2300.0
       Ceiling Conductivity (W/m.K) =                 1.200
       Ceiling Emissivity =                         0.50
       Ceiling Thickness (mm) =                      100.0

       Floor Surface is concrete
       Floor Density (kg/m3) =                       2300.0
       Floor Conductivity (W/m.K) =                   1.200
       Floor Emissivity =                           0.50
       Floor Thickness = (mm)                        100.0

Room  2  : F2 north foyer
       Room Length (m) =                           25.00
       Room Width (m) =                            11.00
       Maximum Room Height (m) =                    4.50
       Minimum Room Height (m) =                    4.50
       Floor Elevation (m) =                        0.000
       Room  2  has a flat ceiling.

       Wall Surface is concrete
       Wall Density (kg/m3) =                        2300.0
       Wall Conductivity (W/m.K) =                    1.200
       Wall Emissivity =                            0.50
       Wall Thickness (mm) =                         100.0

       Ceiling Surface is concrete
       Ceiling Density (kg/m3) =                     2300.0
       Ceiling Conductivity (W/m.K) =                 1.200
       Ceiling Emissivity =                         0.50
       Ceiling Thickness (mm) =                      100.0

       Floor Surface is concrete
       Floor Density (kg/m3) =                       2300.0
       Floor Conductivity (W/m.K) =                   1.200
       Floor Emissivity =                           0.50
       Floor Thickness = (mm)                        100.0

Room  3  : F2 east foyer
       Room Length (m) =                           53.00
       Room Width (m) =                            25.00
       Maximum Room Height (m) =                    4.50
       Minimum Room Height (m) =                    4.50
       Floor Elevation (m) =                        0.000
       Room  3  has a flat ceiling.

Zone models may not provide realistic results for large compartments where momentum effects
and large heat losses remote from the fire could cause non-uniformity in the upper/lower
layer properties. Please interpret your results with extra care.

       Wall Surface is concrete
```

```
        Wall Density (kg/m3) =                          2300.0
        Wall Conductivity (W/m.K) =                      1.200
        Wall Emissivity =                              0.50
        Wall Thickness (mm) =                           100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                       2300.0
        Ceiling Conductivity (W/m.K) =                   1.200
        Ceiling Emissivity =                           0.50
        Ceiling Thickness (mm) =                        100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                         2300.0
        Floor Conductivity (W/m.K) =                     1.200
        Floor Emissivity =                             0.50
        Floor Thickness = (mm)                          100.0

Room  4  : F2 south foyer
        Room Length (m) =                              25.00
        Room Width (m) =                               12.00
        Maximum Room Height (m) =                        4.50
        Minimum Room Height (m) =                        4.50
        Floor Elevation (m) =                           0.000
        Room  4  has a flat ceiling.

        Wall Surface is concrete
        Wall Density (kg/m3) =                          2300.0
        Wall Conductivity (W/m.K) =                      1.200
        Wall Emissivity =                              0.50
        Wall Thickness (mm) =                           100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                       2300.0
        Ceiling Conductivity (W/m.K) =                   1.200
        Ceiling Emissivity =                           0.50
        Ceiling Thickness (mm) =                        100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                         2300.0
        Floor Conductivity (W/m.K) =                     1.200
        Floor Emissivity =                             0.50
        Floor Thickness = (mm)                          100.0

Room  5  : F2 west foyer
        Room Length (m) =                              53.00
        Room Width (m) =                               36.60
        Maximum Room Height (m) =                        4.50
        Minimum Room Height (m) =                        4.50
        Floor Elevation (m) =                           0.000
        Room  5  has a flat ceiling.

Zone models may not provide realistic results for large compartments where momentum effects
and large heat losses remote from the fire could cause non-uniformity in the upper/lower
layer properties. Please interpret your results with extra care.

        Wall Surface is concrete
        Wall Density (kg/m3) =                          2300.0
        Wall Conductivity (W/m.K) =                      1.200
        Wall Emissivity =                              0.50
        Wall Thickness (mm) =                           100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                       2300.0
        Ceiling Conductivity (W/m.K) =                   1.200
        Ceiling Emissivity =                           0.50
        Ceiling Thickness (mm) =                        100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                         2300.0
        Floor Conductivity (W/m.K) =                     1.200
        Floor Emissivity =                             0.50
        Floor Thickness = (mm)                          100.0

Room  6  : F3 north foyer
```

```
        Room Length (m) =                            25.00
        Room Width (m) =                             11.00
        Maximum Room Height (m) =                     4.50
        Minimum Room Height (m) =                     4.50
        Floor Elevation (m) =                        4.500
        Room  6  has a flat ceiling.

        Wall Surface is concrete
        Wall Density (kg/m3) =                        2300.0
        Wall Conductivity (W/m.K) =                    1.200
        Wall Emissivity =                            0.50
        Wall Thickness (mm) =                         100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                     2300.0
        Ceiling Conductivity (W/m.K) =                 1.200
        Ceiling Emissivity =                         0.50
        Ceiling Thickness (mm) =                      100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                       2300.0
        Floor Conductivity (W/m.K) =                   1.200
        Floor Emissivity =                           0.50
        Floor Thickness = (mm)                        100.0

Room  7  : F3 east foyer
        Room Length (m) =                            53.00
        Room Width (m) =                             25.00
        Maximum Room Height (m) =                     4.50
        Minimum Room Height (m) =                     4.50
        Floor Elevation (m) =                        4.500
        Room  7  has a flat ceiling.

Zone models may not provide realistic results for large compartments where momentum effects
and large heat losses remote from the fire could cause non-uniformity in the upper/lower
layer properties. Please interpret your results with extra care.

        Wall Surface is concrete
        Wall Density (kg/m3) =                        2300.0
        Wall Conductivity (W/m.K) =                    1.200
        Wall Emissivity =                            0.50
        Wall Thickness (mm) =                         100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                     2300.0
        Ceiling Conductivity (W/m.K) =                 1.200
        Ceiling Emissivity =                         0.50
        Ceiling Thickness (mm) =                      100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                       2300.0
        Floor Conductivity (W/m.K) =                   1.200
        Floor Emissivity =                           0.50
        Floor Thickness = (mm)                        100.0

Room  8  : F3 south foyer
        Room Length (m) =                            25.00
        Room Width (m) =                             12.00
        Maximum Room Height (m) =                     4.50
        Minimum Room Height (m) =                     4.50
        Floor Elevation (m) =                        4.500
        Room  8  has a flat ceiling.

        Wall Surface is concrete
        Wall Density (kg/m3) =                        2300.0
        Wall Conductivity (W/m.K) =                    1.200
        Wall Emissivity =                            0.50
        Wall Thickness (mm) =                         100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                     2300.0
        Ceiling Conductivity (W/m.K) =                 1.200
        Ceiling Emissivity =                         0.50
        Ceiling Thickness (mm) =                      100.0
```

```
        Floor Surface is concrete
        Floor Density (kg/m3) =                     2300.0
        Floor Conductivity (W/m.K) =                 1.200
        Floor Emissivity =                          0.50
        Floor Thickness = (mm)                      100.0

Room  9  : F3 west foyer
        Room Length (m) =                          53.00
        Room Width (m) =                           36.60
        Maximum Room Height (m) =                    4.50
        Minimum Room Height (m) =                    4.50
        Floor Elevation (m) =                       4.500
        Room  9  has a flat ceiling.

Zone models may not provide realistic results for large compartments where momentum effects
and large heat losses remote from the fire could cause non-uniformity in the upper/lower
layer properties. Please interpret your results with extra care.

        Wall Surface is concrete
        Wall Density (kg/m3) =                      2300.0
        Wall Conductivity (W/m.K) =                  1.200
        Wall Emissivity =                           0.50
        Wall Thickness (mm) =                       100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                    2300.0
        Ceiling Conductivity (W/m.K) =                1.200
        Ceiling Emissivity =                        0.50
        Ceiling Thickness (mm) =                     100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                     2300.0
        Floor Conductivity (W/m.K) =                 1.200
        Floor Emissivity =                          0.50
        Floor Thickness = (mm)                      100.0

Room  10  : medium shop
        Room Length (m) =                          30.00
        Room Width (m) =                           27.00
        Maximum Room Height (m) =                    4.50
        Minimum Room Height (m) =                    4.50
        Floor Elevation (m) =                       0.000
        Room  10  has a flat ceiling.

        Wall Surface is concrete
        Wall Density (kg/m3) =                      2300.0
        Wall Conductivity (W/m.K) =                  1.200
        Wall Emissivity =                           0.50
        Wall Thickness (mm) =                       100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                    2300.0
        Ceiling Conductivity (W/m.K) =                1.200
        Ceiling Emissivity =                        0.50
        Ceiling Thickness (mm) =                     100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                     2300.0
        Floor Conductivity (W/m.K) =                 1.200
        Floor Emissivity =                          0.50
        Floor Thickness = (mm)                      100.0

====================================================================
Wall Vents
====================================================================
From room  1  to  2 , Vent No 1
                Vent Width (m) =                   25.000
                Vent Height (m) =                  4.500
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            4.500
                Opening Time (sec) =               0
                Closing Time (sec) =               0

From room  1  to  3 , Vent No 1
```

```
                Vent Width (m) =                    30.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to  4 , Vent No 1
                Vent Width (m) =                    25.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to  5 , Vent No 1
                Vent Width (m) =                    30.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to  6 , Vent No 1
                Vent Width (m) =                    25.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               4.500
                Vent Soffit Height (m) =             9.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to  7 , Vent No 1
                Vent Width (m) =                    30.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               4.500
                Vent Soffit Height (m) =             9.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to  8 , Vent No 1
                Vent Width (m) =                    25.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               4.500
                Vent Soffit Height (m) =             9.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  1  to  9 , Vent No 1
                Vent Width (m) =                    30.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               4.500
                Vent Soffit Height (m) =             9.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  2  to  3 , Vent No 1
                Vent Width (m) =                    11.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  2  to  5 , Vent No 1
                Vent Width (m) =                    11.000
                Vent Height (m) =                   4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  2  to  10 , Vent No 1
                Vent Width (m) =                    1.720
                Vent Height (m) =                   2.000
```

```
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  3  to  4 , Vent No 1
                Vent Width (m) =                   12.000
                Vent Height (m) =                  4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  3  to outside, Vent No 1
                Vent Width (m) =                   1.720
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

From room  3  to outside, Vent No 2
                Vent Width (m) =                   5.160
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

From room  4  to  5 , Vent No 1
                Vent Width (m) =                   12.000
                Vent Height (m) =                  4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  5  to outside, Vent No 1
                Vent Width (m) =                   1.720
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

From room  5  to outside, Vent No 2
                Vent Width (m) =                   5.160
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

From room  6  to  7 , Vent No 1
                Vent Width (m) =                   11.000
                Vent Height (m) =                  4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  6  to  9 , Vent No 1
                Vent Width (m) =                   11.000
                Vent Height (m) =                  4.500
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             4.500
```

```
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  7  to  8 , Vent No 1
                Vent Width (m) =                   12.000
                Vent Height (m) =                  4.500
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  7  to outside, Vent No 1
                Vent Width (m) =                   1.720
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

From room  7  to outside, Vent No 2
                Vent Width (m) =                   5.160
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

From room  8  to  9 , Vent No 1
                Vent Width (m) =                   12.000
                Vent Height (m) =                  4.500
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            4.500
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  9  to outside, Vent No 1
                Vent Width (m) =                   1.720
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

From room  9  to outside, Vent No 2
                Vent Width (m) =                   5.160
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =                3600
                Closing Time (sec) =                3600
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 10

====================================================================
Ceiling/Floor Vents
====================================================================
====================================================================
Ambient Conditions
====================================================================
Interior Temp (C) =                                 21.0
Exterior Temp (C) =                                 20.0
Relative Humidity (%) =                              65

====================================================================
Tenability Parameters
====================================================================
Monitoring Height for Visibility and FED (m) =          2.00
Occupant Activity Level =                            Light
```

```
Visibility calculations assume:                        illuminated signs
FED Start Time (sec)                                  0
FED End Time (sec)                                    10000

====================================================================
Sprinkler / Detector Parameters
====================================================================
Sprinkler installed in Room                            10
       Sprinkler control is simulated.
       Response Time Index (m.s)^1/2 =                  95.0
       Sprinkler C-Factor (m.s)^1/2 =                   0.40
       Radial Distance (m) =                          2.80
       Actuation Temperature (C) =                     68.0
       Water Spray Density (mm/min) =                  0.0
       Distance below ceiling (mm) =                   20
       Ceiling Jet model used is NIST JET.

Smoke Detector in Room 10
       Smoke Optical Density for Alarm (1/m)            0.097
       Detector Characteristic Length Number (m)        15.0
       Detector Sensitivity (%/ft)                     6.6
       Radial Distance from Plume (m)                  7.000
       Distance below Ceiling (m)                     0.025
       Detector response is based on OD inside the detector chamber.
====================================================================
Mechanical Ventilation (to/from outside)
====================================================================
Mechanical Ventilation installed in Room 1
       Use fan curve
       Fan Elevation (m) =                            12.000
       Start Time (sec) =                             0
       Maximum Cross-Fan Pressure Limit (Pa) =          50
       Number of Fans =                              1
       Extract Rate per fan (m3/s) =                    75.00
Mechanical Ventilation not installed in Room 2
Mechanical Ventilation not installed in Room 3
Mechanical Ventilation not installed in Room 4
Mechanical Ventilation not installed in Room 5
Mechanical Ventilation not installed in Room 6
Mechanical Ventilation not installed in Room 7
Mechanical Ventilation not installed in Room 8
Mechanical Ventilation not installed in Room 9
Mechanical Ventilation not installed in Room 10

====================================================================
Description of the Fire
====================================================================
Radiant Loss Fraction =                                0.35
CO Yield pre-flashover(g/g) =                           0.040
CO Yield post-flashover(g/g) =                          0.400
Soot Yield pre-flashover(g/g) =                         0.070
Soot Yield post-flashover(g/g) =                        0.140
Smoke Emission Coefficient (1/m) =                      1.20
Characteristic Mass Loss per Unit Area (kg/s.m2) =        0.011
Air Entrainment in Plume uses McCaffrey (default)

Burning Object No 1

           Located in Room                            10
           Energy Yield (kJ/g) =                       20.0
           CO2 Yield (kg/kg fuel) =                     1.920
           HCN Yield (kg/kg fuel) =                     0.000
           Fire Height (m) =                          0.400
           Fire Location =                            Centre

           Time (sec)             Heat Release (kW)
            0                    0
            30                   42
            60                   169
            90                   381
            120                  677
            150                  1058
            180                  1523
            210                  2073
```

```
          240                   2707
          270                   3426
          300                   4230
          330                   5118
          360                   6091
          390                   7149
          420                   8291
          450                   9518
          480                   10829
          652                   20000
         1800                   20000

====================================================================
Postflashover Inputs
====================================================================
Postflashover model is OFF.
```

4. Retail Warehouse – Retail Fire

```
BRANZFIRE Multi-Compartment Fire Model (Ver 2010.5)

Retail fire(roller doors,D10 shut, slide door s/c)

====================================================================
Description of Rooms
====================================================================
Room  1  : Retail
       Room Length (m) =                           43.80
       Room Width (m) =                            37.20
       Maximum Room Height (m) =                    8.00
       Minimum Room Height (m) =                    8.00
       Floor Elevation (m) =                        0.000
       Room  1  has a flat ceiling.

Zone models may not provide realistic results for large compartments where momentum effects
and large heat losses remote from the fire could cause non-uniformity in the upper/lower
layer properties. Please interpret your results with extra care.

       Wall Surface is concrete
       Wall Density (kg/m3) =                       2300.0
       Wall Conductivity (W/m.K) =                   1.200
       Wall Emissivity =                           0.50
       Wall Thickness (mm) =                        100.0

       Ceiling Surface is steel (mild)
       Ceiling Density (kg/m3) =                    7850.0
       Ceiling Conductivity (W/m.K) =                45.800
       Ceiling Emissivity =                        0.90
       Ceiling Thickness (mm) =                     6.0

       Floor Surface is concrete
       Floor Density (kg/m3) =                      2300.0
       Floor Conductivity (W/m.K) =                  1.200
       Floor Emissivity =                          0.50
       Floor Thickness = (mm)                       100.0

Room  2  : Stock Room
       Room Length (m) =                           35.60
       Room Width (m) =                            8.60
       Maximum Room Height (m) =                    8.00
       Minimum Room Height (m) =                    8.00
       Floor Elevation (m) =                        0.000
       Room  2  has a flat ceiling.

       Wall Surface is concrete
       Wall Density (kg/m3) =                       2300.0
       Wall Conductivity (W/m.K) =                   1.200
       Wall Emissivity =                           0.50
       Wall Thickness (mm) =                        100.0

       Ceiling Surface is steel (mild)
```

```
        Ceiling Density (kg/m3) =                      7850.0
        Ceiling Conductivity (W/m.K) =                  45.800
        Ceiling Emissivity =                          0.90
        Ceiling Thickness (mm) =                       6.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                        2300.0
        Floor Conductivity (W/m.K) =                    1.200
        Floor Emissivity =                            0.50
        Floor Thickness = (mm)                         100.0

Room  3  : Drive Thru
        Room Length (m) =                            39.00
        Room Width (m) =                             10.50
        Maximum Room Height (m) =                      8.00
        Minimum Room Height (m) =                      8.00
        Floor Elevation (m) =                         0.000
        Room  3  has a flat ceiling.

        Wall Surface is concrete
        Wall Density (kg/m3) =                         2300.0
        Wall Conductivity (W/m.K) =                     1.200
        Wall Emissivity =                             0.50
        Wall Thickness (mm) =                          100.0

        Ceiling Surface is steel (mild)
        Ceiling Density (kg/m3) =                      7850.0
        Ceiling Conductivity (W/m.K) =                  45.800
        Ceiling Emissivity =                          0.90
        Ceiling Thickness (mm) =                       6.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                        2300.0
        Floor Conductivity (W/m.K) =                    1.200
        Floor Emissivity =                            0.50
        Floor Thickness = (mm)                         100.0

Room  4  : Staircase
        Room Length (m) =                            7.50
        Room Width (m) =                             1.20
        Maximum Room Height (m) =                      5.90
        Minimum Room Height (m) =                      5.90
        Floor Elevation (m) =                         0.000
        Room  4  has a flat ceiling.

        Wall Surface is concrete
        Wall Density (kg/m3) =                         2300.0
        Wall Conductivity (W/m.K) =                     1.200
        Wall Emissivity =                             0.50
        Wall Thickness (mm) =                          100.0

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                      2300.0
        Ceiling Conductivity (W/m.K) =                  1.200
        Ceiling Emissivity =                          0.50
        Ceiling Thickness (mm) =                       100.0

        Floor Surface is concrete
        Floor Density (kg/m3) =                        2300.0
        Floor Conductivity (W/m.K) =                    1.200
        Floor Emissivity =                            0.50
        Floor Thickness = (mm)                         100.0

====================================================================
Wall Vents
====================================================================
From room  1  to  2 , Vent No 1
                Vent Width (m) =                     0.810
                Vent Height (m) =                    2.000
                Vent Sill Height (m) =                0.000
                Vent Soffit Height (m) =              2.000
                Opening Time (sec) =                 0
                Closing Time (sec) =                 0
```

```
From room  1  to  2 , Vent No 2
                Vent Width (m) =                   0.035
                Vent Height (m) =                  8.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            8.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0

From room  1  to  3 , Vent No 1
                Vent Width (m) =                   2.000
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  1  to  3 , Vent No 2
                Vent Width (m) =                   0.035
                Vent Height (m) =                  8.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            8.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0

From room  1  to outside, Vent No 1
                Vent Width (m) =                   0.810
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  1  to outside, Vent No 2
                Vent Width (m) =                   0.810
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  1  to outside, Vent No 3
                Vent Width (m) =                   0.063
                Vent Height (m) =                  8.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            8.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0

From room  2  to  4 , Vent No 1
                Vent Width (m) =                   0.440
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0
                This vent can automatically open with the following trigger(s)

From room  2  to outside, Vent No 1
                Vent Width (m) =                   0.410
                Vent Height (m) =                  2.000
                Vent Sill Height (m) =              0.000
                Vent Soffit Height (m) =            2.000
                Opening Time (sec) =               0
                Closing Time (sec) =               0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  3  to outside, Vent No 1
```

```
                Vent Width (m) =                    0.410
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  3  to outside, Vent No 2
                Vent Width (m) =                    0.410
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

From room  3  to outside, Vent No 3
                Vent Width (m) =                    0.053
                Vent Height (m) =                   8.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             8.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0

From room  4  to outside, Vent No 1
                Vent Width (m) =                    0.440
                Vent Height (m) =                   2.000
                Vent Sill Height (m) =               0.000
                Vent Soffit Height (m) =             2.000
                Opening Time (sec) =                0
                Closing Time (sec) =                0
                This vent can automatically open with the following trigger(s)
                Smoke Detection in Room 1

=====================================================================
Ceiling/Floor Vents
=====================================================================
Upper outside  to lower room 1 , Vent No 1
                Vent Area (m2) =                    256.00
                Opening Time (sec) =                712  (upper T reach 250°C)
                Closing Time (sec) =                10000
                Open method =                      Manual

=====================================================================
Ambient Conditions
=====================================================================
Interior Temp (C) =                                 21.0
Exterior Temp (C) =                                 20.0
Relative Humidity (%) =                              65

=====================================================================
Tenability Parameters
=====================================================================
Monitoring Height for Visibility and FED (m) =          2.00
Occupant Activity Level =                            Light
Visibility calculations assume:                       illuminated signs
FED Start Time (sec)                                0
FED End Time (sec)                                  10000

=====================================================================
Sprinkler / Detector Parameters
=====================================================================
No thermal detector or sprinkler installed.
Smoke Detector in Room 1
        Smoke Optical Density for Alarm (1/m)           0.097
        Detector Characteristic Length Number (m)        15.0
        Detector Sensitivity (%/ft)                    6.6
        Radial Distance from Plume (m)                 7.000
        Distance below Ceiling (m)                     0.025
        Detector response is based on OD inside the detector chamber.
=====================================================================
```

```
Mechanical Ventilation (to/from outside)
====================================================================
Mechanical Ventilation not installed in Room 1
Mechanical Ventilation not installed in Room 2
Mechanical Ventilation not installed in Room 3
Mechanical Ventilation not installed in Room 4
Mechanical Ventilation not installed in Room 5

====================================================================
Description of the Fire
====================================================================
Radiant Loss Fraction =                                  0.35
CO Yield pre-flashover(g/g) =                             0.040
CO Yield post-flashover(g/g) =                            0.400
Soot Yield pre-flashover(g/g) =                           0.070
Soot Yield post-flashover(g/g) =                          0.140
Smoke Emission Coefficient (1/m) =                        1.20
Characteristic Mass Loss per Unit Area (kg/s.m2) =          0.011
Air Entrainment in Plume uses McCaffrey (default)

Burning Object No 1

           Located in Room                        1
           Energy Yield (kJ/g) =                   20.0
           CO2 Yield (kg/kg fuel) =                1.920
           HCN Yield (kg/kg fuel) =                0.000
           Fire Height (m) =                      0.400
           Fire Location =                        Centre

           Time (sec)            Heat Release (kW)
            0                  0
            30                 42
            60                 169
            90                 381
            120                677
            150                1058
            180                1523
            210                2073
            240                2707
            270                3426
            300                4230
            330                5118
            360                6091
            390                7149
            420                8291
            450                9518
            480                10829
            652                20000
           1800                20000

====================================================================
Postflashover Inputs
====================================================================
Postflashover model is OFF.
```

APPENDIX I Design for Smoke Reservoir of Shopping Mall

Ambient temperature:	To=	20	^{o}C	
Height of fuel:		0.4	m	(as per C/AS1)
Ceiling height above the fuel	H=	11.6	m	

Heat release rate $\dot{Q} = 0.047t^2$ (Fast fire as per C/AS1)

Atrium floor area : S= 750 m^2

Height of the layer interface above the fuel $z = (\frac{k}{S} 0.047^{1/3} \frac{2}{5} t^{5/3} + \frac{1}{H^{2/3}})^{-3/2}$

Where, $k = \frac{0.21}{\rho_g} (\frac{\rho_a^2 g}{c_p T_a})^{1/3}$, $t = 180s$

Given ρ_g a guess value : $1.0kg/m^3$

$\rho_a = 1.2kg/m^3$

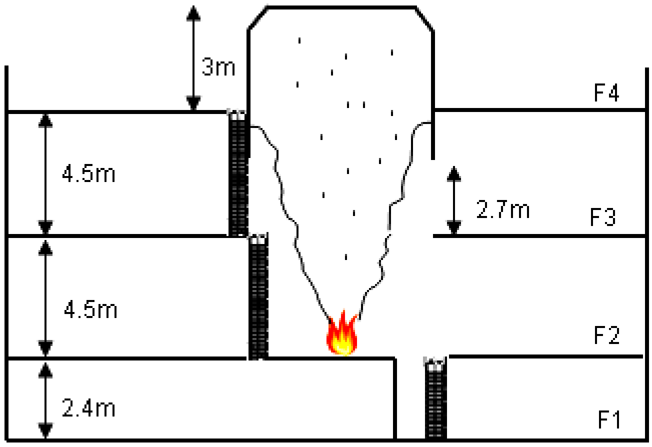
Hence: $k = 0.0764$

$z = 6.8m$

Therefore, the smoke reservoir shall have a depth of 4.8 m.

APPENDIX J   Design for Smoke Exhaust System of Shopping Mall

The smoke layer in the atrium space is shown as below. The mechanical extract system is designed to maintain a smoke layer at a height of 2.7 m above Floor 3.



Ambient temperature   To=   20 ^oC

Height of fuel   0.4   m   (as per framework)

Height of the smoke layer interface above the fuel   z=   6.8   m

Smoke layer depth   4.8   m

Steady heat release rate   20000   kW   (as per framework)

Convective fraction   0.65   (as per framework)

Wall heat transfer fraction   0.4   (Klote & Milke 2002)

The convective heat release rate is

Qc=   13000   kW

The mean flame height is

$$z_1 = 0.166 Q_c^{2/5} = \quad 7.3 \text{ m}$$

As $z_1 > z$, the mass flow is

$$\dot{m} = 0.032 Q_c^{3/5} z = \quad 64 \text{ kg/s}$$

The smoke temperature is

$$T_s = T_o + \frac{Q_c(1-\eta)}{\dot{m} C_p} = \quad 141.9 \text{ C}$$

The smoke density is

$$\rho_s = \rho_r \frac{T_r}{T_s} = \quad 0.9 \text{kg/m3}$$

The volumetric flow of exhaust gases is

$$\dot{V} = \frac{\dot{m}}{\rho_p} = \quad 75 \text{ m}^3/\text{s}$$

Ventilation area of make-up air for mechanical smoke extract is based on a maximum air velocity of 5m/s as per C/AS1.

$m_{inlet} = m_{extract} = 64kg/s$

The volumetric flow of inlet air is

$$\dot{V}_{air} = \frac{\dot{m}_{air}}{\rho_{air}} = \frac{64kg/s}{1.2kg/m^3} = 53m^3/s$$

$A_{inlet} = 10.6m^2$

The maximum volumetric flow rate that can be efficiently extracted using a single exhaust inlet is calculated using the method by Klote & Milke (2002).

$\dot{V}_{max} = 0.00887\beta d^{5/2}\sqrt{T_o(T_s - T_o)} = 237m^3/s$

Where $\beta = 2.8$ for a ceiling exhaust inlet far away from wall

d is smoke layer depth which is 4.8 m

$\dot{V}_{exhaust} = 75m^3/s < \dot{V}_{max}$ Therefore, only one extract point is required.

APPENDIX K Egress Calculation of the Shopping Mall

1. For room of origin

Retail Floor						
clear Large shop						
	travel time			queuing time		
L1:	travel	55	m	total occupants:	605	
(queuing	travel speed:	1.2	m/s	combined effective door width:	3.4	m
	travel time:	46	s	Specific flow:	4.42	ppl/s
				queuing time:	**137**	s
L2:	travel	70	m	total occupants:	901	
(queuing	travel speed:	1.2	m/s	combined effective door width:	5.68	m
	travel time:	58	s	Specific flow:	7.384	ppl/s
				queuing time:	122	s
clear medium shop						
	travel time			queuing time		
M1:	travel	49	m	total occupants:	252	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.68	m
	travel time:	41	s	Specific flow:	2.184	ppl/s
				queuing time:	115	s
M2:	travel	47	m	total occupants:	243	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.12	m
	travel time:	39	s	Specific flow:	1.456	ppl/s
				queuing time:	**167**	s
M3:	travel	43	m	total occupants:	203	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.12	m
	travel time:	36	s	Specific flow:	1.456	ppl/s
				queuing time:	139	s
M4:	travel	35	m	total occupants:	192	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.12	m
	travel time:	29	s	Specific flow:	1.456	ppl/s
				queuing time:	132	s
M5:	travel	49.5	m	total occupants:	198	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.12	m
	travel time:	41	s	Specific flow:	1.456	ppl/s
				queuing time:	136	s
M6:	travel	44	m	total occupants:	195	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.12	m
	travel time:	37	s	Specific flow:	1.456	ppl/s
				queuing time:	134	s
M7:	travel	45.5	m	total occupants:	211	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.12	m
	travel time:	38	s	Specific flow:	1.456	ppl/s
				queuing time:	145	s
M8:	travel	45.5	m	total occupants:	203	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.12	m
	travel time:	38	s	Specific flow:	1.456	ppl/s
				queuing time:	139	s
M9:	travel	49	m	total occupants:	267	
(queuing	travel speed:	1.2	m/s	combined effective door width:	1.68	m
	travel time:	41	s	Specific flow:	2.184	ppl/s
				queuing time:	122	s
M10:	travel	51	m	total occupants:	222	

(queuing	travel speed: 1.2 m/s travel time: 43 s	combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: 152 s
clear small shop		
	travel time	queuing time
S1: (queuing	travel 22 m travel speed: 1.2 m/s travel time: 18 s	total occupants: 71 combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: 49 s
S2: (queuing	travel 25 m travel speed: 1.2 m/s travel time: 21 s	total occupants: 72 combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: 49 s
S3: (queuing	travel 26 m travel speed: 1.2 m/s travel time: 22 s	total occupants: 47 combined effective door width: 0.56 m Specific flow: 0.728 ppl/s queuing time: 65 s
S4: (queuing	travel 26 m travel speed: 1.2 m/s travel time: 22 s	total occupants: 47 combined effective door width: 0.56 m Specific flow: 0.728 ppl/s queuing time: 65 s
S5: (queuing	travel 22 m travel speed: 1.2 m/s travel time: 18 s	total occupants: 61 combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: 42 s
S6: (queuing	travel 24 m travel speed: 1.2 m/s travel time: 20 s	total occupants: 70 combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: 48 s
S7: (queuing	travel 26 m travel speed: 1.2 m/s travel time: 22 s	total occupants: 47 combined effective door width: 0.56 m Specific flow: 0.728 ppl/s queuing time: 65 s
S8: (queuing	travel 27 m travel speed: 1.2 m/s travel time: 23 s	total occupants: 50 combined effective door width: 0.56 m Specific flow: 0.728 ppl/s queuing time: 69 s
S9: (queuing	travel 27 m travel speed: 1.2 m/s travel time: 23 s	total occupants: 74 combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: **51** s
S10: (queuing	travel 22 m travel speed: 1.2 m/s travel time: 18 s	total occupants: 71 combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: 49 s
clear restaurant		
(queuing	travel 32.5 m travel speed: 1.2 m/s travel time: 27 s	total occupants: 200 combined effective door width: 1.12 m Specific flow: 1.456 ppl/s queuing time: 137 s

2. Stair capacity

Specific flow for each internal stair

effective width of stair: 3.2 m

specific flow on stair: 3.008 ppl/s (0.94 ppl/s/m)

combined effective width of doors into stair: 2.84 m

specific flow through stair door: 3.692 ppl/s (1.3 ppl/s/m)

Hence: prime control factor is the stairway

Specific flow for two main entrance (same for Floor 2 & 3)

Prime control factor is the entrance doors, congestion on external stairs are not considered which is much wider than entrance doors

total combined effective width of both entrances: 17.04 m

total specific flow through two main entries: 22.15 ppl/s

Total capacity of internal stairs

each staircase

area: 80 m^2

density: 1.9 ppl/m^2 (at maximum discharge flow)

capacity: 152 ppl

total capacity of 6 staircase on each retail floor 912 ppl

total capacity of staircases(level 1-3) 2736 ppl

Note: 1. Floor 4 not counted for capacity as no egress upward;

2. Stair capacity on the top floor shall be compared with occupant loads of the top level, whichever is less shall be used. For lower floors, capacity shall not greater than the total occupant loads of all upper floors.

3. Large shop (L1) fire on Floor 2

Travel time from L1 to staircases

travel distance	35	m
travel speed (density<0.54 ppl/m^2)	1.2	m/s
travel time	29	s

Hence: after 89s (60s+29s), L1 occupants start entering staircases at a flow rate same as flow out of shop L1 until 120s (which is 4.42 ppl/s).

Time for stairs starting to discharge ppl to outside

travel distance on stair from F2 to F1

conversion factor	1.66	
floor height	2.4	m
landing	3	m
travel distance	10.0	m
travel speed on stair (when density < 0.54 ppl/m^2)	0.85	m/s
travel time	12	s

density (at maximum flow)	1.9	ppl/m2	
k (for stairway)	1		
travel speed on stair	0.5	m/s	($S = k - \alpha k D$)
travel time	20	s	

Hence: 1. after 101s (89s+10s), stairs start to discharge people into ground floor at a flow rate same as flow out of L1 until 140s (which is 4.42 ppl/s)

2. after 140s (120s+20s), stairs start clear ppl at maximum discharge flow

Time	Number of occupants into circulation (Floor2)																											Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																											Floor 2				Floor 3				
(s)	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
60	(end of premovement of fire origin)																											<120s	>120s							
61	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
62	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
63	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0
64	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0
65	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0
66	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0
67	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0
68	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0
69	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0
70	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0
71	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0
72	53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	0	0	0	0	0	0	0	0	0
73	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	0	0	0	0	0	0
74	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0
75	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0
76	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71	0	0	0	0	0	0	0	0	0
77	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75	0	0	0	0	0	0	0	0	0
78	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0	0
79	84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84	0	0	0	0	0	0	0	0	0
80	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88	0	0	0	0	0	0	0	0	0
81	93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93	0	0	0	0	0	0	0	0	0
82	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0	0	0	0	0	0	0	0	0
83	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102	0	0	0	0	0	0	0	0	0
84	106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	106	0	0	0	0	0	0	0	0	0
85	111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111	0	0	0	0	0	0	0	0	0
86	115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	115	0	0	0	0	0	0	0	0	0
87	119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	119	0	0	0	0	0	0	0	0	0
88	124	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	124	0	0	0	0	0	0	0	0	0
89	128	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0
90	133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	133	4	0	0	4	0	0	0	0	4
91	137	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	137	9	0	0	9	0	0	0	0	9
92	141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	141	13	0	0	13	0	0	0	0	13
93	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	146	18	0	0	18	0	0	0	0	18
94	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	150	22	0	0	22	0	0	0	0	22
95	155	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	155	27	0	0	27	0	0	0	0	27
96	159	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	159	31	0	0	31	0	0	0	0	31
97	164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	164	35	0	0	35	0	0	0	0	35
98	168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	168	40	0	0	40	0	0	0	0	40
99	172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	172	44	0	0	44	0	0	0	0	44
100	177	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	177	49	0	0	49	0	0	0	0	49
101	181	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	181	53	0	0	53	0	0	0	0	53
102	186	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	186	57	0	0	57	0	0	0	4	53
103	190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	190	62	0	0	62	0	0	0	9	53
104	194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	194	66	0	0	66	0	0	0	13	53
105	199	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	199	71	0	0	71	0	0	0	18	53
106	203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	203	75	0	0	75	0	0	0	22	53
107	208	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	208	80	0	0	80	0	0	0	27	53
108	212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	212	84	0	0	84	0	0	0	31	53
109	217	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	217	88	0	0	88	0	0	0	35	53
110	221	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	221	93	0	0	93	0	0	0	40	53

Time (s)	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																										Floor 2				Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
111	225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	225	97	0	0	97	0	0	0	44	53
112	230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	230	102	0	0	102	0	0	0	49	53
113	234	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	234	106	0	0	106	0	0	0	53	53
114	239	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	239	111	0	0	111	0	0	0	57	54
115	243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	243	115	0	0	115	0	0	0	62	53
116	248	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	248	119	0	0	119	0	0	0	66	53
117	252	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	252	124	0	0	124	0	0	0	71	53
118	256	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	256	128	0	0	128	0	0	0	75	53
119	261	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	261	133	0	0	133	0	0	0	80	53
120	265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	265	137	0	0	137	0	0	0	84	53
121	270	7	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1152	180	50	1682	137	22	22	181	22	22	44	88	93
122	274	15	4	3	3	3	3	3	3	3	4	3	3	3	1	1	3	3	1	1	3	3	3	1152	180	50	1728	137	44	44	225	44	44	88	93	132
123	278	22	7	4	4	4	4	4	4	4	7	4	4	4	2	2	4	4	2	2	4	4	4	1152	180	50	1764	137	66	66	269	66	66	132	97	172
124	283	30	9	6	6	6	6	6	6	6	9	6	6	6	3	3	6	6	3	3	6	6	6	1152	180	50	1815	137	89	89	315	89	89	178	102	213
125	287	37	11	7	7	7	7	7	7	7	11	7	7	7	4	4	7	7	4	4	7	7	7	1152	180	50	1849	137	111	111	359	111	111	222	106	253
126	292	44	13	9	9	9	9	9	9	9	13	9	9	9	4	4	9	9	4	4	9	9	9	1152	180	50	1895	137	133	133	403	133	133	266	111	292
127	296	52	15	10	10	10	10	10	10	10	15	10	10	10	5	5	10	10	5	5	10	10	10	1152	180	50	1930	137	155	155	447	155	155	310	115	332
128	301	59	17	12	12	12	12	12	12	12	17	12	12	12	6	6	12	12	6	6	12	12	12	1152	180	50	1980	137	177	177	491	177	177	354	119	372
129	305	66	20	13	13	13	13	13	13	13	20	13	13	13	7	7	13	13	7	7	13	13	13	1152	180	50	2016	137	199	199	535	199	199	398	124	411
130	309	74	22	15	15	15	15	15	15	15	22	15	15	15	7	7	15	15	7	7	15	15	15	1152	180	50	2062	137	222	222	581	222	222	444	128	453
131	314	81	24	16	16	16	16	16	16	16	24	16	16	16	8	8	16	16	8	8	16	16	16	1152	180	50	2097	137	244	244	625	244	244	488	133	492
132	318	89	26	17	17	17	17	17	17	17	26	17	17	17	9	9	17	17	9	9	17	17	17	1152	180	50	2132	137	266	266	669	266	266	532	137	532
133	323	96	28	19	19	19	19	19	19	19	28	19	19	19	9	9	19	19	9	9	19	19	19	1152	180	50	2178	137	288	288	713	288	288	576	141	572
134	327	103	31	20	20	20	20	20	20	20	31	20	20	20	10	10	20	20	10	10	20	20	20	1152	180	50	2214	137	310	310	757	310	310	620	146	611
135	332	111	33	22	22	22	22	22	22	22	33	22	22	22	11	11	22	22	11	11	22	22	22	1152	180	50	2265	137	332	332	801	332	332	664	150	651
136	336	118	35	23	23	23	23	23	23	23	35	23	23	23	12	12	23	23	12	12	23	23	23	1152	180	50	2299	137	354	354	845	354	354	708	155	690
137	340	126	37	25	25	25	25	25	25	25	37	25	25	25	12	12	25	25	12	12	25	25	25	1152	180	50	2345	137	377	377	891	377	377	754	159	732
138	345	133	39	26	26	26	26	26	26	26	39	26	26	26	13	13	26	26	13	13	26	26	26	1152	180	50	2380	137	399	399	935	399	399	798	164	771
139	349	140	41	28	28	28	28	28	28	28	41	28	28	28	14	14	28	28	14	14	28	28	28	1152	180	50	2429	137	421	421	979	421	421	842	168	811
140	354	148	44	29	29	29	29	29	29	29	44	29	29	29	15	15	29	29	15	15	29	29	29	1152	180	50	2467	137	443	443	1023	443	443	886	172	851
210	605	665	197	131	131	131	131	131	131	131	197	131	71	72	47	47	61	70	47	50	74	71	131	1152	180	50	4835	137	1994	1994	4125	1994	1994	3988	1435	2690
211	605	672	199	132	132	132	132	132	132	132	199	132	71	72	47	47	61	70	47	50	74	71	132	1152	180	50	4855	137	2016	2016	4169	2016	2016	4032	1453	2716
212	605	679	201	134	134	134	134	134	134	134	201	134	71	72	47	47	61	70	47	50	74	71	134	1152	180	50	4884	137	2035	2038	4210	2035	2038	4073	1471	2736
213	605	687	203	135	135	135	135	135	135	135	203	135	71	72	47	47	61	70	47	50	74	71	135	1152	180	50	4905	137	2044	2060	4241	2044	2060	4104	1490	2735
214	605	694	205	137	137	137	137	137	137	137	205	137	71	72	47	47	61	70	47	50	74	71	137	1152	180	50	4934	137	2053	2082	4272	2053	2082	4135	1508	2735
215	605	701	207	138	138	138	138	138	138	138	207	138	71	72	47	47	61	70	47	50	74	71	138	1152	180	50	4954	137	2062	2104	4303	2062	2104	4166	1526	2735
216	605	709	210	140	140	140	140	140	140	140	210	140	71	72	47	47	61	70	47	50	74	71	140	1152	180	50	4986	137	2071	2126	4334	2071	2126	4197	1544	2735
217	605	716	212	141	141	141	141	141	141	141	212	141	71	72	47	47	61	70	47	50	74	71	141	1152	180	50	5006	137	2080	2149	4366	2080	2149	4229	1562	2735
218	605	724	214	143	143	143	143	143	143	143	214	143	71	72	47	47	61	70	47	50	74	71	143	1152	180	50	5036	137	2089	2171	4397	2089	2171	4260	1580	2735
219	605	731	216	144	144	144	144	144	144	144	216	144	71	72	47	47	61	70	47	50	74	71	144	1152	180	50	5056	137	2098	2193	4428	2098	2193	4291	1598	2735
220	605	738	218	146	146	146	146	146	146	146	218	146	71	72	47	47	61	70	47	50	74	71	146	1152	180	50	5085	137	2107	2215	4459	2107	2215	4322	1616	2735
260	605	901	252	204	203	192	198	195	204	203	267	204	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5820	137	2468	3101	5706	2468	3101	5569	2338	2735
261	605	901	252	205	203	192	198	195	205	203	267	205	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5823	137	2477	3123	5737	2477	3123	5600	2356	2735
262	605	901	252	207	203	192	198	195	207	203	267	207	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5829	137	2486	3145	5768	2486	3145	5631	2374	2735
263	605	901	252	208	203	192	198	195	208	203	267	208	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5832	137	2495	3167	5799	2495	3167	5662	2392	2735
264	605	901	252	210	203	192	198	195	210	203	267	210	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5838	137	2504	3190	5831	2504	3190	5694	2410	2735
265	605	901	252	211	203	192	198	195	211	203	267	211	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5841	137	2513	3212	5862	2513	3191	5704	2428	2735
266	605	901	252	213	203	192	198	195	211	203	267	213	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5845	137	2513	3234	5884	2513	3191	5704	2446	2717
267	605	901	252	214	203	192	198	195	211	203	267	214	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5847	137	2513	3234	5884	2513	3191	5704	2464	2699
268	605	901	252	215	203	192	198	195	211	203	267	215	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5849	137	2513	3234	5884	2513	3191	5704	2482	2681
269	605	901	252	217	203	192	198	195	211	203	267	217	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5853	137	2513	3234	5884	2513	3191	5704	2500	2663

Time (s)	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																										Floor 2				Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
270	605	901	252	218	203	192	198	195	211	203	267	218	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5855	137	2513	3234	5884	2513	3191	5704	2518	2645
400	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4864	299
401	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4883	280
402	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4901	262
403	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4919	244
404	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4937	226
405	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4955	208
406	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4973	190
407	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	4991	172
408	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5009	154
409	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5027	136
410	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5045	118
411	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5063	100
412	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5081	82
413	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5099	64
414	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5117	46
415	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5135	28
416	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5153	10
417	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	137	2513	3234	5884	2513	3191	5704	5163	0

Last ppl travel from stairway to outside on ground floor

travel distance:	81	m
travel speed:	1.2	m/s
travel time:	68	s

time clear entire building to outside 485 s

4. Medium shop (M2) fire on Floor 2

Travel time from Shop M2 to stairway

travel distance	58	m
travel speed (density<0.54 ppl/m^2)	1.2	m/s
travel time	48	s

Hence: 1. after 108s (60+48s), M2 occupants start entering staircases at flow rate same as flow out of M2 until 120s

2. after 120s (108s+12s), stairs start to discharge people into ground floor at a flow rate same as flow out of M2 until 140s (which is 1.456 ppl/s)

3. after 140s (120s+20s), stairs at maximum discharge flow

Time	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear	ppl
	Floor 2																										Floor 2				Floor 3			from	remain
(s)	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total	stairs	in stair
60	(end of premovement of fire origin)																											<120s	>120s							
61	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
62	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
63	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
64	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
65	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
66	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
67	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0
68	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0
69	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0
70	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0
71	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
72	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0
73	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0
74	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0
75	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0
76	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0
77	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0
78	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0
79	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0
80	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0
81	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0
82	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0
83	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0
84	0	0	0	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0
85	0	0	0	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0
86	0	0	0	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0
87	0	0	0	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	0	0	0	0	0	0	0	0	0
88	0	0	0	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	0	0	0	0	0	0	0	0
89	0	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	0	0	0	0	0	0	0	0	0
90	0	0	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0
91	0	0	0	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0
92	0	0	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	0	0	0	0	0	0	0	0
93	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0
94	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0
95	0	0	0	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0
96	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0
97	0	0	0	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0	0	0	0	0	0	0	0	0
98	0	0	0	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	0	0	0	0	0	0	0	0	0
99	0	0	0	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	0	0	0	0	0	0
100	0	0	0	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0	0	0	0	0	0	0	0
101	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0
102	0	0	0	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	0	0	0	0	0	0	0	0	0
103	0	0	0	63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0	0	0	0	0	0	0	0
104	0	0	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0	0
105	0	0	0	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0
106	0	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0	0	0	0	0	0	0
107	0	0	0	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0	0	0	0	0	0	0	0	0
108	0	0	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0	0	0
109	0	0	0	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71	1	0	0	1	0	0	0	0	1
110	0	0	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	3	0	0	3	0	0	0	0	3

Time	Number of occupants into circulation (Floor2)																											Number of occupants cleared							ppl clear	ppl
	Floor 2																											Floor 2				Floor 3			from	remain
(s)	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total	stairs	in stair
111	0	0	0	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	4	0	0	4	0	0	0	0	4
112	0	0	0	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	6	0	0	6	0	0	0	0	6
113	0	0	0	77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	7	0	0	7	0	0	0	0	7
114	0	0	0	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79	9	0	0	9	0	0	0	0	9
115	0	0	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	10	0	0	10	0	0	0	0	10
116	0	0	0	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	12	0	0	12	0	0	0	0	12
117	0	0	0	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	83	13	0	0	13	0	0	0	0	13
118	0	0	0	84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84	15	0	0	15	0	0	0	0	15
119	0	0	0	86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	16	0	0	16	0	0	0	0	16
120	0	0	0	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87	17	0	0	17	0	0	0	0	17
121	4	7	2	89	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1152	180	50	1504	17	22	22	61	22	22	44	1	60
122	9	15	4	90	3	3	3	3	3	3	4	3	3	3	1	1	3	3	1	1	3	3	3	1152	180	50	1550	17	44	44	105	44	44	88	3	102
123	13	22	7	92	4	4	4	4	4	4	7	4	4	4	2	2	4	4	2	2	4	4	4	1152	180	50	1587	17	66	66	149	66	66	132	4	145
124	18	30	9	93	6	6	6	6	6	6	9	6	6	6	3	3	6	6	3	3	6	6	6	1152	180	50	1637	17	89	89	195	89	89	178	6	189
125	22	37	11	95	7	7	7	7	7	7	11	7	7	7	4	4	7	7	4	4	7	7	7	1152	180	50	1672	17	111	111	239	111	111	222	7	232
126	27	44	13	96	9	9	9	9	9	9	13	9	9	9	4	4	9	9	4	4	9	9	9	1152	180	50	1717	17	133	133	283	133	133	266	9	274
127	31	52	15	98	10	10	10	10	10	10	15	10	10	10	5	5	10	10	5	5	10	10	10	1152	180	50	1753	17	155	155	327	155	155	310	10	317
128	35	59	17	99	12	12	12	12	12	12	17	12	12	12	6	6	12	12	6	6	12	12	12	1152	180	50	1801	17	177	177	371	177	177	354	12	359
129	40	66	20	100	13	13	13	13	13	13	20	13	13	13	7	7	13	13	7	7	13	13	13	1152	180	50	1838	17	199	199	415	199	199	398	13	402
130	44	74	22	102	15	15	15	15	15	15	22	15	15	15	7	7	15	15	7	7	15	15	15	1152	180	50	1884	17	222	222	461	222	222	444	15	446
131	49	81	24	103	16	16	16	16	16	16	24	16	16	16	8	8	16	16	8	8	16	16	16	1152	180	50	1919	17	244	244	505	244	244	488	16	489
132	53	89	26	105	17	17	17	17	17	17	26	17	17	17	9	9	17	17	9	9	17	17	17	1152	180	50	1955	17	266	266	549	266	266	532	17	532
133	57	96	28	106	19	19	19	19	19	19	28	19	19	19	9	9	19	19	9	9	19	19	19	1152	180	50	1999	17	288	288	593	288	288	576	19	574
134	62	103	31	108	20	20	20	20	20	20	31	20	20	20	10	10	20	20	10	10	20	20	20	1152	180	50	2037	17	310	310	637	310	310	620	20	617
135	66	111	33	109	22	22	22	22	22	22	33	22	22	22	11	11	22	22	11	11	22	22	22	1152	180	50	2086	17	332	332	681	332	332	664	22	659
136	71	118	35	111	23	23	23	23	23	23	35	23	23	23	12	12	23	23	12	12	23	23	23	1152	180	50	2122	17	354	354	725	354	354	708	23	702
137	75	126	37	112	25	25	25	25	25	25	37	25	25	25	12	12	25	25	12	12	25	25	25	1152	180	50	2167	17	377	377	771	377	377	754	25	746
138	80	133	39	114	26	26	26	26	26	26	39	26	26	26	13	13	26	26	13	13	26	26	26	1152	180	50	2203	17	399	399	815	399	399	798	26	789
139	84	140	41	115	28	28	28	28	28	28	41	28	28	28	14	14	28	28	14	14	28	28	28	1152	180	50	2251	17	421	421	859	421	421	842	28	831
140	88	148	44	116	29	29	29	29	29	29	44	29	29	29	15	15	29	29	15	15	29	29	29	1152	180	50	2288	17	443	443	903	443	443	886	29	874
210	398	665	197	218	131	131	131	131	131	131	197	131	71	72	47	47	61	70	47	50	74	71	131	1152	180	50	4715	17	1994	1994	4005	1994	1994	3988	1292	2713
211	402	672	199	220	132	132	132	132	132	132	199	132	71	72	47	47	61	70	47	50	74	71	132	1152	180	50	4740	17	2016	2016	4049	2008	2016	4024	1310	2731
212	407	679	201	221	134	134	134	134	134	134	201	134	71	72	47	47	61	70	47	50	74	71	134	1152	180	50	4773	17	2030	2038	4085	2017	2038	4055	1328	2736
213	411	687	203	223	135	135	135	135	135	135	203	135	71	72	47	47	61	70	47	50	74	71	135	1152	180	50	4799	17	2039	2060	4116	2026	2060	4086	1347	2735
214	415	694	205	224	137	137	137	137	137	137	205	137	71	72	47	47	61	70	47	50	74	71	137	1152	180	50	4831	17	2048	2082	4147	2035	2082	4117	1365	2735
215	420	701	207	226	138	138	138	138	138	138	207	138	71	72	47	47	61	70	47	50	74	71	138	1152	180	50	4857	17	2057	2104	4178	2044	2104	4148	1383	2735
216	424	709	210	227	140	140	140	140	140	140	210	140	71	72	47	47	61	70	47	50	74	71	140	1152	180	50	4892	17	2066	2126	4209	2053	2126	4179	1401	2735
217	429	716	212	229	141	141	141	141	141	141	212	141	71	72	47	47	61	70	47	50	74	71	141	1152	180	50	4918	17	2075	2149	4241	2062	2149	4211	1419	2735
218	433	724	214	230	143	143	143	143	143	143	214	143	71	72	47	47	61	70	47	50	74	71	143	1152	180	50	4951	17	2084	2171	4272	2071	2171	4242	1437	2735
219	438	731	216	232	144	144	144	144	144	144	216	144	71	72	47	47	61	70	47	50	74	71	144	1152	180	50	4977	17	2093	2193	4303	2080	2193	4273	1455	2735
220	442	738	218	233	146	146	146	146	146	146	218	146	71	72	47	47	61	70	47	50	74	71	146	1152	180	50	5009	17	2102	2215	4334	2089	2215	4304	1473	2735
260	605	901	252	243	203	192	198	195	204	203	267	204	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5859	17	2463	3101	5581	2450	3101	5551	2195	2735
261	605	901	252	243	203	192	198	195	205	203	267	205	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5861	17	2472	3123	5612	2459	3123	5582	2213	2735
262	605	901	252	243	203	192	198	195	207	203	267	207	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5865	17	2481	3145	5643	2468	3145	5613	2231	2735
263	605	901	252	243	203	192	198	195	208	203	267	208	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5867	17	2490	3167	5674	2477	3167	5644	2249	2735
264	605	901	252	243	203	192	198	195	210	203	267	210	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5871	17	2499	3190	5706	2486	3190	5676	2267	2735
265	605	901	252	243	203	192	198	195	211	203	267	211	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5873	17	2508	3212	5737	2492	3212	5704	2285	2732
266	605	901	252	243	203	192	198	195	211	203	267	213	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5875	17	2526	3234	5777	2492	3212	5704	2303	2732
267	605	901	252	243	203	192	198	195	211	203	267	214	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5876	17	2544	3256	5817	2492	3212	5704	2321	2732
268	605	901	252	243	203	192	198	195	211	203	267	215	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5877	17	2562	3278	5857	2492	3212	5704	2339	2732
269	605	901	252	243	203	192	198	195	211	203	267	217	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5879	17	2567	3300	5884	2492	3212	5704	2357	2719

Time	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear	ppl
	Floor 2																										Floor 2				Floor 3			from	remain
(s)	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total	stairs	in stair
270	605	901	252	243	203	192	198	195	211	203	267	218	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5880	17	2567	3300	5884	2492	3212	5704	2375	2701
400	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4721	355
401	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4740	336
402	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4758	318
403	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4776	300
404	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4794	282
405	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4812	264
406	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4830	246
407	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4848	228
408	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4866	210
409	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4884	192
410	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4902	174
411	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4920	156
412	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4938	138
413	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4956	120
414	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4974	102
415	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	4992	84
416	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	5010	66
417	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	5028	48
418	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	5046	30
419	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	5064	12
420	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	17	2567	3300	5884	2492	3212	5704	5076	0

Last ppl travel from stairway to outside on ground floor

travel distance:	81	m
travel speed:	1.2	m/s
travel time:	68	s
time clear entire building to outside	488	s

5. Small shop (S9) fire on Floor 2

Travel time from S9 to stairway

travel distance 65 m

travel speed (density<0.54ppl/m^2) 1.2 m/s

travel time 54 s

Hence: 1. after 114s (60+54s), S9 occupants start entering staircases at flow rate same as flow out of S9 until 120s (1.456ppl/s)

2. after 126s (114s+12s), stair start to discharge people into ground floor at a flow rate same as flow out of S9 until 140s (1.456 ppl/s)

3. after 140s (120s+20s), stairs at maximum discharge flow

Time (s)	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																										Floor 2				Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
60	(end of premovement of fire origin)																											<120s	>120s							
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	0	0	0	0	0	39	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	0	0	0	0	41	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	0	0	0	0	0	42	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	0	0	0	0	47	0	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0	0	0	0	0	54	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	0	0	0	0	0	55	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	0	0	57	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0	0	0	0	58	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	0	0	0	0	0	61	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0	0	0	0	63	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0	64	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0	0	0	67	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0	0	0	0	0	68	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	70	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71	0	0	0	0	0	71	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	73	0	0	0	0	0	0	0	0	0

Time (s)	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																										Floor 2				Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	1	0	0	1	0	0	0	0	1
116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	3	0	0	3	0	0	0	0	3
117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	4	0	0	4	0	0	0	0	4
118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	6	0	0	6	0	0	0	0	6
119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	7	0	0	7	0	0	0	0	7
120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	74	9	0	0	9	0	0	0	0	9
121	4	7	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	74	1	1	1152	180	50	1489	9	22	22	53	22	22	44	0	53
122	9	15	4	3	3	3	3	3	3	3	4	3	3	3	1	1	3	3	1	1	74	3	3	1152	180	50	1534	9	44	44	97	44	44	88	0	97
123	13	22	7	4	4	4	4	4	4	4	7	4	4	4	2	2	4	4	2	2	74	4	4	1152	180	50	1569	9	66	66	141	66	66	132	0	141
124	18	30	9	6	6	6	6	6	6	6	9	6	6	6	3	3	6	6	3	3	74	6	6	1152	180	50	1618	9	89	89	187	89	89	178	0	187
125	22	37	11	7	7	7	7	7	7	7	11	7	7	7	4	4	7	7	4	4	74	7	7	1152	180	50	1651	9	111	111	231	111	111	222	0	231
126	27	44	13	9	9	9	9	9	9	9	13	9	9	9	4	4	9	9	4	4	74	9	9	1152	180	50	1695	9	133	133	275	133	133	266	0	275
127	31	52	15	10	10	10	10	10	10	10	15	10	10	10	5	5	10	10	5	5	74	10	10	1152	180	50	1729	9	155	155	319	155	155	310	1	318
128	35	59	17	12	12	12	12	12	12	12	17	12	12	12	6	6	12	12	6	6	74	12	12	1152	180	50	1776	9	177	177	363	177	177	354	3	360
129	40	66	20	13	13	13	13	13	13	13	20	13	13	13	7	7	13	13	7	7	74	13	13	1152	180	50	1812	9	199	199	407	199	199	398	4	403
130	44	74	22	15	15	15	15	15	15	15	22	15	15	15	7	7	15	15	7	7	74	15	15	1152	180	50	1856	9	222	222	453	222	222	444	6	447
131	49	81	24	16	16	16	16	16	16	16	24	16	16	16	8	8	16	16	8	8	74	16	16	1152	180	50	1890	9	244	244	497	244	244	488	7	490
132	53	89	26	17	17	17	17	17	17	17	26	17	17	17	9	9	17	17	9	9	74	17	17	1152	180	50	1924	9	266	266	541	266	266	532	9	532
133	57	96	28	19	19	19	19	19	19	19	28	19	19	19	9	9	19	19	9	9	74	19	19	1152	180	50	1967	9	288	288	585	288	288	576	10	575
134	62	103	31	20	20	20	20	20	20	20	31	20	20	20	10	10	20	20	10	10	74	20	20	1152	180	50	2003	9	310	310	629	310	310	620	12	617
135	66	111	33	22	22	22	22	22	22	22	33	22	22	22	11	11	22	22	11	11	74	22	22	1152	180	50	2051	9	332	332	673	332	332	664	13	660
136	71	118	35	23	23	23	23	23	23	23	35	23	23	23	12	12	23	23	12	12	74	23	23	1152	180	50	2085	9	354	354	717	354	354	708	15	702
137	75	126	37	25	25	25	25	25	25	25	37	25	25	25	12	12	25	25	12	12	74	25	25	1152	180	50	2129	9	377	377	763	377	377	754	16	747
138	80	133	39	26	26	26	26	26	26	26	39	26	26	26	13	13	26	26	13	13	74	26	26	1152	180	50	2163	9	399	399	807	399	399	798	17	790
139	84	140	41	28	28	28	28	28	28	28	41	28	28	28	14	14	28	28	14	14	74	28	28	1152	180	50	2210	9	421	421	851	421	421	842	19	832
140	88	148	44	29	29	29	29	29	29	29	44	29	29	29	15	15	29	29	15	15	74	29	29	1152	180	50	2246	9	443	443	895	443	443	886	20	875
210	398	665	197	131	131	131	131	131	131	131	197	131	71	72	47	47	61	70	47	50	74	71	131	1152	180	50	4628	9	1994	1994	3997	1994	1994	3988	1283	2714
211	402	672	199	132	132	132	132	132	132	132	199	132	71	72	47	47	61	70	47	50	74	71	132	1152	180	50	4652	9	2014	2016	4039	2014	2016	4030	1301	2736
212	407	679	201	134	134	134	134	134	134	134	201	134	71	72	47	47	61	70	47	50	74	71	134	1152	180	50	4686	9	2023	2038	4070	2023	2038	4061	1319	2736
213	411	687	203	135	135	135	135	135	135	135	203	135	71	72	47	47	61	70	47	50	74	71	135	1152	180	50	4711	9	2032	2060	4101	2032	2060	4092	1338	2735
214	415	694	205	137	137	137	137	137	137	137	205	137	71	72	47	47	61	70	47	50	74	71	137	1152	180	50	4744	9	2041	2082	4132	2041	2082	4123	1356	2735
215	420	701	207	138	138	138	138	138	138	138	207	138	71	72	47	47	61	70	47	50	74	71	138	1152	180	50	4769	9	2050	2104	4163	2050	2104	4154	1374	2735
216	424	709	210	140	140	140	140	140	140	140	210	140	71	72	47	47	61	70	47	50	74	71	140	1152	180	50	4805	9	2059	2126	4194	2059	2126	4185	1392	2735
217	429	716	212	141	141	141	141	141	141	141	212	141	71	72	47	47	61	70	47	50	74	71	141	1152	180	50	4830	9	2068	2149	4226	2068	2149	4217	1410	2735
218	433	724	214	143	143	143	143	143	143	143	214	143	71	72	47	47	61	70	47	50	74	71	143	1152	180	50	4864	9	2077	2171	4257	2077	2171	4248	1428	2735
219	438	731	216	144	144	144	144	144	144	144	216	144	71	72	47	47	61	70	47	50	74	71	144	1152	180	50	4889	9	2086	2193	4288	2086	2193	4279	1446	2735
220	442	738	218	146	146	146	146	146	146	146	218	146	71	72	47	47	61	70	47	50	74	71	146	1152	180	50	4922	9	2095	2215	4319	2095	2215	4310	1464	2735
260	605	901	252	204	203	192	198	195	204	203	267	204	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5820	9	2456	3101	5566	2456	3101	5557	2186	2735
261	605	901	252	205	203	192	198	195	205	203	267	205	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5823	9	2465	3123	5597	2465	3123	5588	2204	2735
262	605	901	252	207	203	192	198	195	207	203	267	207	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5829	9	2474	3145	5628	2474	3145	5619	2222	2735
263	605	901	252	208	203	192	198	195	208	203	267	208	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5832	9	2483	3167	5659	2483	3167	5650	2240	2735
264	605	901	252	210	203	192	198	195	210	203	267	210	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5838	9	2492	3190	5691	2492	3190	5682	2258	2735
265	605	901	252	211	203	192	198	195	211	203	267	211	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5841	9	2510	3212	5731	2501	3203	5704	2276	2744
266	605	901	252	213	203	192	198	195	211	203	267	213	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5845	9	2528	3234	5771	2501	3203	5704	2294	2744
267	605	901	252	214	203	192	198	195	211	203	267	214	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5847	9	2546	3256	5811	2501	3203	5704	2312	2744
268	605	901	252	215	203	192	198	195	211	203	267	215	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5849	9	2564	3278	5851	2501	3203	5704	2330	2744
269	605	901	252	217	203	192	198	195	211	203	267	217	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5853	9	2575	3300	5884	2501	3203	5704	2348	2737

Time (s)	Number of occupants into circulation (Floor2)																											Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																											Floor 2				Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
270	605	901	252	218	203	192	198	195	211	203	267	218	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5855	9	2575	3300	5884	2501	3203	5704	2366	2719
400	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4712	373
401	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4731	354
402	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4749	336
403	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4767	318
404	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4785	300
405	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4803	282
406	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4821	264
407	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4839	246
408	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4857	228
409	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4875	210
410	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4893	192
411	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4911	174
412	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4929	156
413	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4947	138
414	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4965	120
415	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	4983	102
416	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	5001	84
417	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	5019	66
418	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	5037	48
419	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	5055	30
420	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	5073	12
421	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	9	2575	3300	5884	2501	3203	5704	5085	0

Last ppl travel from stairway to outside on ground floor

travel distance: 81 m

travel speed: 1.2 m/s

travel time: 68 s

time clear entire building to outside 489 s

6. Restaurant fire on Floor 2

Travel time from restaurant to stairway			**Travel time from restaurant to main entry**		
travel distance	47	m	travel distance	15	m
travel speed (density<0.54)	1.2	m/s	travel speed(density<0.54)	1.2	m/s
travel time	39	s	travel time	13	s

Hence: (assume half occupants of restaurant clear from stair and half clear from main entrance)

1. after 73s (60s+13s), restaurant occupants start clear from main entrance at flow rate same as half flow out of restaurant until 120s (0.728ppl/s)
2. after 99s (60s+39s), restaurant occupants start entering staircase at flow rate same as half flow out of restaurant until 120s (0.728ppl/s)
3. after 111s (99s+12s), stair starts to discharge people into ground floor at a flow rate same as half flow out of restaurant until 140s (1.456 ppl/s)
4. after 140s (120s+20s), stairs at maximum discharge flow

Time	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear from stairs	ppl remain in stair
(s)	Floor 2																										Floor 2				Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
60	(end of premovement of fire origin)																											<120s	>120s							
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	4	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	6	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	7	0	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	9	0	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	12	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	13	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	15	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	16	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	17	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	19	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	20	0	0	1	1	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	22	0	0	1	1	0	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	23	0	0	2	2	0	0	0	0	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	25	0	0	3	3	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	26	0	0	4	4	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	28	0	0	4	4	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	29	0	0	5	5	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	31	0	0	6	6	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	32	0	0	7	7	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	33	0	0	7	7	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	35	0	0	8	8	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	36	0	0	9	9	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	0	0	38	0	0	9	9	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	0	0	0	39	0	0	10	10	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	0	0	41	0	0	11	11	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	0	0	0	42	0	0	12	12	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0	44	0	0	12	12	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	45	0	0	13	13	0	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	0	0	47	0	0	14	14	0	0	0	0	0
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	48	0	0	15	15	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	50	0	0	15	15	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	51	0	0	16	16	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0	52	0	0	17	17	0	0	0	0	0
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0	0	0	54	0	0	17	17	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	0	0	0	55	0	0	18	18	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	57	0	0	19	19	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	0	0	0	58	1	0	20	21	0	0	0	0	1
101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	60	1	0	20	21	0	0	0	0	1
102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	0	0	0	61	2	0	21	23	0	0	0	0	2
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0	0	63	3	0	22	25	0	0	0	0	3
104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0	64	4	0	23	27	0	0	0	0	4
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0	66	4	0	23	27	0	0	0	0	4
106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0	67	5	0	24	29	0	0	0	0	5
107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0	0	0	68	6	0	25	31	0	0	0	0	6
108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	70	7	0	25	32	0	0	0	0	7
109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71	0	0	0	71	7	0	26	33	0	0	0	0	7
110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	73	8	0	27	35	0	0	0	0	8

Time (s)	Number of occupants into circulation (Floor2)																											Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																											Floor 2				Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	0	0	0	74	9	0	28	37	0	0	0	0	9
112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	0	0	0	76	9	0	28	37	0	0	0	1	8
113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	0	0	0	77	10	0	29	39	0	0	0	1	9
114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79	0	0	0	79	11	0	30	41	0	0	0	2	9
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	80	12	0	31	43	0	0	0	3	9
116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	0	0	0	82	12	0	31	43	0	0	0	4	8
117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	83	0	0	0	83	13	0	32	45	0	0	0	4	9
118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84	0	0	0	84	14	0	33	47	0	0	0	5	9
119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	0	0	0	86	15	0	33	48	0	0	0	6	9
120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87	0	0	0	87	15	0	34	49	0	0	0	7	8
121	4	7	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	89	1152	180	50	1504	15	22	56	93	22	22	44	7	52
122	9	15	4	3	3	3	3	3	3	3	4	3	3	3	1	1	3	3	1	1	3	3	90	1152	180	50	1550	15	44	78	137	44	44	88	8	95
123	13	22	7	4	4	4	4	4	4	4	7	4	4	4	2	2	4	4	2	2	4	4	92	1152	180	50	1587	15	66	100	181	66	66	132	9	138
124	18	30	9	6	6	6	6	6	6	6	9	6	6	6	3	3	6	6	3	3	6	6	93	1152	180	50	1637	15	89	123	227	89	89	178	9	184
125	22	37	11	7	7	7	7	7	7	7	11	7	7	7	4	4	7	7	4	4	7	7	95	1152	180	50	1672	15	111	145	271	111	111	222	10	227
126	27	44	13	9	9	9	9	9	9	9	13	9	9	9	4	4	9	9	4	4	9	9	96	1152	180	50	1717	15	133	167	315	133	133	266	11	270
127	31	52	15	10	10	10	10	10	10	10	15	10	10	10	5	5	10	10	5	5	10	10	98	1152	180	50	1753	15	155	189	359	155	155	310	12	313
128	35	59	17	12	12	12	12	12	12	12	17	12	12	12	6	6	12	12	6	6	12	12	99	1152	180	50	1801	15	177	211	403	177	177	354	12	357
129	40	66	20	13	13	13	13	13	13	13	20	13	13	13	7	7	13	13	7	7	13	13	100	1152	180	50	1838	15	199	233	447	199	199	398	13	400
130	44	74	22	15	15	15	15	15	15	15	22	15	15	15	7	7	15	15	7	7	15	15	102	1152	180	50	1884	15	222	256	493	222	222	444	14	445
131	49	81	24	16	16	16	16	16	16	16	24	16	16	16	8	8	16	16	8	8	16	16	103	1152	180	50	1919	15	244	278	537	244	244	488	15	488
132	53	89	26	17	17	17	17	17	17	17	26	17	17	17	9	9	17	17	9	9	17	17	105	1152	180	50	1955	15	266	300	581	266	266	532	15	532
133	57	96	28	19	19	19	19	19	19	19	28	19	19	19	9	9	19	19	9	9	19	19	106	1152	180	50	1999	15	288	322	625	288	288	576	16	575
134	62	103	31	20	20	20	20	20	20	20	31	20	20	20	10	10	20	20	10	10	20	20	108	1152	180	50	2037	15	310	344	669	310	310	620	17	618
135	66	111	33	22	22	22	22	22	22	22	33	22	22	22	11	11	22	22	11	11	22	22	109	1152	180	50	2086	15	332	366	713	332	332	664	17	662
136	71	118	35	23	23	23	23	23	23	23	35	23	23	23	12	12	23	23	12	12	23	23	111	1152	180	50	2122	15	354	388	757	354	354	708	18	705
137	75	126	37	25	25	25	25	25	25	25	37	25	25	25	12	12	25	25	12	12	25	25	112	1152	180	50	2167	15	377	411	803	377	377	754	19	750
138	80	133	39	26	26	26	26	26	26	26	39	26	26	26	13	13	26	26	13	13	26	26	114	1152	180	50	2203	15	399	433	847	399	399	798	20	793
139	84	140	41	28	28	28	28	28	28	28	41	28	28	28	14	14	28	28	14	14	28	28	115	1152	180	50	2251	15	421	455	891	421	421	842	20	837
140	88	148	44	29	29	29	29	29	29	29	44	29	29	29	15	15	29	29	15	15	29	29	116	1152	180	50	2288	15	443	477	935	443	443	886	21	880
210	398	665	197	131	131	131	131	131	131	131	197	131	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4697	15	1994	2028	4037	1994	1994	3988	1284	2719
211	402	672	199	132	132	132	132	132	132	132	199	132	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4720	15	2016	2050	4081	2005	2016	4021	1302	2734
212	407	679	201	134	134	134	134	134	134	134	201	134	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4752	15	2027	2072	4114	2014	2038	4052	1320	2736
213	411	687	203	135	135	135	135	135	135	135	203	135	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4776	15	2036	2094	4145	2023	2060	4083	1339	2735
214	415	694	205	137	137	137	137	137	137	137	205	137	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4807	15	2045	2116	4176	2032	2082	4114	1357	2735
215	420	701	207	138	138	138	138	138	138	138	207	138	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4831	15	2054	2138	4207	2041	2104	4145	1375	2735
216	424	709	210	140	140	140	140	140	140	140	210	140	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4865	15	2063	2160	4238	2050	2126	4176	1393	2735
217	429	716	212	141	141	141	141	141	141	141	212	141	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4889	15	2072	2183	4270	2059	2149	4208	1411	2735
218	433	724	214	143	143	143	143	143	143	143	214	143	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4921	15	2081	2205	4301	2068	2171	4239	1429	2735
219	438	731	216	144	144	144	144	144	144	144	216	144	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4945	15	2090	2227	4332	2077	2193	4270	1447	2735
220	442	738	218	146	146	146	146	146	146	146	218	146	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	4976	15	2099	2249	4363	2086	2215	4301	1465	2735
260	605	901	252	204	203	192	198	195	204	203	267	204	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5820	15	2460	3135	5610	2447	3101	5548	2187	2735
261	605	901	252	205	203	192	198	195	205	203	267	205	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5823	15	2469	3157	5641	2456	3123	5579	2205	2735
262	605	901	252	207	203	192	198	195	207	203	267	207	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5829	15	2478	3179	5672	2465	3145	5610	2223	2735
263	605	901	252	208	203	192	198	195	208	203	267	208	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5832	15	2487	3201	5703	2474	3167	5641	2241	2735
264	605	901	252	210	203	192	198	195	210	203	267	210	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5838	15	2496	3224	5735	2483	3190	5673	2259	2735
265	605	901	252	211	203	192	198	195	211	203	267	211	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5841	15	2514	3246	5775	2492	3212	5704	2277	2744
266	605	901	252	213	203	192	198	195	211	203	267	213	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5845	15	2532	3268	5815	2492	3212	5704	2295	2744
267	605	901	252	214	203	192	198	195	211	203	267	214	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5847	15	2550	3290	5855	2492	3212	5704	2313	2744
268	605	901	252	215	203	192	198	195	211	203	267	215	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5849	15	2557	3312	5884	2492	3212	5704	2331	2733
269	605	901	252	217	203	192	198	195	211	203	267	217	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5853	15	2557	3312	5884	2492	3212	5704	2349	2715

Time	Number of occupants into circulation (Floor2)																										Number of occupants cleared							ppl clear from stairs	ppl remain in stair
	Floor 2																										Floor 2				Floor 3				
(s)	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stair	stairs	Main entries	Total	stairs	spiral stairs	Total		
270	605	901	252	218	203	192	198	195	211	203	267	218	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5855	15	2557	3312	5884	2492	3212	5704	2367	2697
400	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4713	351
401	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4732	332
402	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4750	314
403	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4768	296
404	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4786	278
405	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4804	260
406	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4822	242
407	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4840	224
408	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4858	206
409	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4876	188
410	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4894	170
411	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4912	152
412	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4930	134
413	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4948	116
414	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4966	98
415	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	4984	80
416	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	5002	62
417	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	5020	44
418	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	5038	26
419	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	5056	8
420	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	15	2557	3312	5884	2492	3212	5704	5064	0

Last ppl travel from stairway to outside on ground floor		
travel distance:	81	m
travel speed:	1.2	m/s
travel time:	68	s
time clear entire building to outside	488	s

7. Atrium fire on Floor 2

1. after 80s (60s+20s), stairs at maximum discharge flow until all occupants in atrium & foyer cleared
2. after 140s (120s+20s), stairs at maximum discharge flow again

Time	Number of occupants into circulation (Floor2)																											Number of occupants cleared						ppl clear from stairs	ppl remain in stair
	Floor 2																											Floor2			Floor 3				
(s)	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stairs	Main entries	Total	stairs	spiral stairs	Total		
60	(end of premovement of fire origin)																																		
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	22	22	44	0	0	0	0	22
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	44	44	88	0	0	0	0	44
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	66	66	132	0	0	0	0	66
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	89	89	178	0	0	0	0	89
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	111	111	222	0	0	0	0	111
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	133	133	266	0	0	0	0	133
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	155	155	310	0	0	0	0	155
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	177	177	354	0	0	0	0	177
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	199	199	398	0	0	0	0	199
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	222	222	444	0	0	0	0	222
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	244	244	488	0	0	0	0	244
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	266	266	532	0	0	0	0	266
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	288	288	576	0	0	0	0	288
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	310	310	620	0	0	0	0	310
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	332	332	664	0	0	0	0	332
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	354	354	708	0	0	0	0	354
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	377	377	754	0	0	0	0	377
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	399	399	798	0	0	0	0	399
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	421	421	842	0	0	0	0	421
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	443	443	886	0	0	0	0	443
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	465	465	930	0	0	0	18	447
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	487	487	974	0	0	0	36	451
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	509	509	1018	0	0	0	54	455
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	532	532	1064	0	0	0	72	460
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	554	554	1108	0	0	0	90	464
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	576	576	1152	0	0	0	108	468
87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	598	598	1196	0	0	0	126	472
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	620	620	1240	0	0	0	144	476
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	642	642	1284	0	0	0	162	480
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	665	665	1330	0	0	0	180	485
91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	687	687	1374	0	0	0	199	488
92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	217	474
93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	235	456
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	253	438
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	271	420
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	289	402
97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	307	384
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	325	366
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	343	348
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	361	330
101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	379	312
102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	397	294
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	415	276
104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	433	258
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	451	240
106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	469	222
107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	487	204
108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	505	186
109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	523	168
110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	541	150

Time	Number of occupants into circulation (Floor2)																										Number of occupants cleared						ppl clear	ppl
	Floor 2																										Floor2			Floor 3			from	remain
(s)	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stairs	Main entries	Total	stairs	spiral stairs	Total	stairs	in stair
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	559	132
112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	578	113
113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	596	95
114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	614	77
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	632	59
116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	650	41
117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	668	23
118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	686	5
119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	691	0
120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1152	180	50	1382	691	691	1382	0	0	0	691	0
121	4	7	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1152	180	50	1416	713	713	1426	22	22	44	691	44
122	9	15	4	3	3	3	3	3	3	3	4	3	3	3	1	1	3	3	1	1	3	3	3	1152	180	50	1463	735	735	1470	44	44	88	691	88
123	13	22	7	4	4	4	4	4	4	4	7	4	4	4	2	2	4	4	2	2	4	4	4	1152	180	50	1499	757	757	1514	66	66	132	691	132
124	18	30	9	6	6	6	6	6	6	6	9	6	6	6	3	3	6	6	3	3	6	6	6	1152	180	50	1550	780	780	1560	89	89	178	691	178
125	22	37	11	7	7	7	7	7	7	7	11	7	7	7	4	4	7	7	4	4	7	7	7	1152	180	50	1584	802	802	1604	111	111	222	691	222
126	27	44	13	9	9	9	9	9	9	9	13	9	9	9	4	4	9	9	4	4	9	9	9	1152	180	50	1630	824	824	1648	133	133	266	691	266
127	31	52	15	10	10	10	10	10	10	10	15	10	10	10	5	5	10	10	5	5	10	10	10	1152	180	50	1665	846	846	1692	155	155	310	691	310
128	35	59	17	12	12	12	12	12	12	12	17	12	12	12	6	6	12	12	6	6	12	12	12	1152	180	50	1714	868	868	1736	177	177	354	691	354
129	40	66	20	13	13	13	13	13	13	13	20	13	13	13	7	7	13	13	7	7	13	13	13	1152	180	50	1751	890	890	1780	199	199	398	691	398
130	44	74	22	15	15	15	15	15	15	15	22	15	15	15	7	7	15	15	7	7	15	15	15	1152	180	50	1797	913	913	1826	222	222	444	691	444
131	49	81	24	16	16	16	16	16	16	16	24	16	16	16	8	8	16	16	8	8	16	16	16	1152	180	50	1832	935	935	1870	244	244	488	691	488
132	53	89	26	17	17	17	17	17	17	17	26	17	17	17	9	9	17	17	9	9	17	17	17	1152	180	50	1867	957	957	1914	266	266	532	691	532
133	57	96	28	19	19	19	19	19	19	19	28	19	19	19	9	9	19	19	9	9	19	19	19	1152	180	50	1912	979	979	1958	288	288	576	691	576
134	62	103	31	20	20	20	20	20	20	20	31	20	20	20	10	10	20	20	10	10	20	20	20	1152	180	50	1949	1001	1001	2002	310	310	620	691	620
135	66	111	33	22	22	22	22	22	22	22	33	22	22	22	11	11	22	22	11	11	22	22	22	1152	180	50	1999	1023	1023	2046	332	332	664	691	664
136	71	118	35	23	23	23	23	23	23	23	35	23	23	23	12	12	23	23	12	12	23	23	23	1152	180	50	2034	1045	1045	2090	354	354	708	691	708
137	75	126	37	25	25	25	25	25	25	25	37	25	25	25	12	12	25	25	12	12	25	25	25	1152	180	50	2080	1068	1068	2136	377	377	754	691	754
138	80	133	39	26	26	26	26	26	26	26	39	26	26	26	13	13	26	26	13	13	26	26	26	1152	180	50	2115	1090	1090	2180	399	399	798	691	798
139	84	140	41	28	28	28	28	28	28	28	41	28	28	28	14	14	28	28	14	14	28	28	28	1152	180	50	2164	1112	1112	2224	421	421	842	691	842
140	88	148	44	29	29	29	29	29	29	29	44	29	29	29	15	15	29	29	15	15	29	29	29	1152	180	50	2201	1134	1134	2268	443	443	886	691	886
210	398	665	197	131	131	131	131	131	131	131	197	131	71	72	47	47	61	70	47	50	74	71	131	1152	180	50	4628	2685	2685	5370	1994	1994	3988	1954	2725
211	402	672	199	132	132	132	132	132	132	132	199	132	71	72	47	47	61	70	47	50	74	71	132	1152	180	50	4652	2700	2707	5407	2008	2016	4024	1972	2736
212	407	679	201	134	134	134	134	134	134	134	201	134	71	72	47	47	61	70	47	50	74	71	134	1152	180	50	4686	2709	2729	5438	2017	2038	4055	1990	2736
213	411	687	203	135	135	135	135	135	135	135	203	135	71	72	47	47	61	70	47	50	74	71	135	1152	180	50	4711	2718	2751	5469	2026	2060	4086	2009	2735
214	415	694	205	137	137	137	137	137	137	137	205	137	71	72	47	47	61	70	47	50	74	71	137	1152	180	50	4744	2727	2773	5500	2035	2082	4117	2027	2735
215	420	701	207	138	138	138	138	138	138	138	207	138	71	72	47	47	61	70	47	50	74	71	138	1152	180	50	4769	2736	2795	5531	2044	2104	4148	2045	2735
216	424	709	210	140	140	140	140	140	140	140	210	140	71	72	47	47	61	70	47	50	74	71	140	1152	180	50	4805	2745	2817	5562	2053	2126	4179	2063	2735
217	429	716	212	141	141	141	141	141	141	141	212	141	71	72	47	47	61	70	47	50	74	71	141	1152	180	50	4830	2754	2840	5594	2062	2149	4211	2081	2735
218	433	724	214	143	143	143	143	143	143	143	214	143	71	72	47	47	61	70	47	50	74	71	143	1152	180	50	4864	2763	2862	5625	2071	2171	4242	2099	2735
219	438	731	216	144	144	144	144	144	144	144	216	144	71	72	47	47	61	70	47	50	74	71	144	1152	180	50	4889	2772	2884	5656	2080	2193	4273	2117	2735
220	442	738	218	146	146	146	146	146	146	146	218	146	71	72	47	47	61	70	47	50	74	71	146	1152	180	50	4922	2781	2906	5687	2089	2215	4304	2135	2735
221	446	746	221	147	147	147	147	147	147	147	221	147	71	72	47	47	61	70	47	50	74	71	147	1152	180	50	4949	2790	2928	5718	2098	2237	4335	2153	2735
222	451	753	223	149	149	149	149	149	149	149	223	149	71	72	47	47	61	70	47	50	74	71	149	1152	180	50	4983	2799	2950	5749	2107	2259	4366	2171	2735
223	455	761	225	150	150	150	150	150	150	150	225	150	71	72	47	47	61	70	47	50	74	71	150	1152	180	50	5008	2808	2972	5780	2116	2281	4397	2189	2735
224	460	768	227	151	151	151	151	151	151	151	227	151	71	72	47	47	61	70	47	50	74	71	151	1152	180	50	5033	2817	2995	5812	2125	2304	4429	2207	2735
225	464	775	229	153	153	153	153	153	153	153	229	153	71	72	47	47	61	70	47	50	74	71	153	1152	180	50	5066	2826	3017	5843	2134	2326	4460	2225	2735
226	469	783	232	154	154	154	154	154	154	154	232	154	71	72	47	47	61	70	47	50	74	71	154	1152	180	50	5094	2835	3039	5874	2143	2348	4491	2243	2735
227	473	790	234	156	156	156	156	156	156	156	234	156	71	72	47	47	61	70	47	50	74	71	156	1152	180	50	5127	2835	3049	5884	2161	2370	4531	2261	2735
228	477	797	236	157	157	157	157	157	157	157	236	157	71	72	47	47	61	70	47	50	74	71	157	1152	180	50	5151	2835	3049	5884	2179	2392	4571	2279	2735
229	482	805	238	159	159	159	159	159	159	159	238	159	71	72	47	47	61	70	47	50	74	71	159	1152	180	50	5186	2835	3049	5884	2197	2414	4611	2297	2735
230	486	812	240	160	160	160	160	160	160	160	240	160	71	72	47	47	61	70	47	50	74	71	160	1152	180	50	5210	2835	3049	5884	2215	2437	4652	2315	2735

Time (s)	Number of occupants into circulation (Floor2)																										Number of occupants cleared						ppl clear from stairs	ppl remain in stair
	Floor 2																										Floor2			Floor 3				
	L1	L2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Restaurant	Circulation	Atrium	Foodcourt	Total	stairs	Main entries	Total	stairs	spiral stairs	Total		
250	575	901	252	189	189	189	189	189	189	189	267	189	71	72	47	47	61	70	47	50	74	71	189	1152	180	50	5688	2835	3049	5884	2576	2880	5456	2676	2735
251	579	901	252	191	191	191	191	191	191	191	267	191	71	72	47	47	61	70	47	50	74	71	191	1152	180	50	5710	2835	3049	5884	2594	2902	5496	2694	2735
252	583	901	252	192	192	192	192	192	192	192	267	192	71	72	47	47	61	70	47	50	74	71	192	1152	180	50	5723	2835	3049	5884	2612	2924	5536	2712	2735
253	588	901	252	194	194	192	194	194	194	194	267	194	71	72	47	47	61	70	47	50	74	71	194	1152	180	50	5744	2835	3049	5884	2630	2946	5576	2730	2735
254	592	901	252	195	195	192	195	195	195	195	267	195	71	72	47	47	61	70	47	50	74	71	195	1152	180	50	5756	2835	3049	5884	2648	2968	5616	2748	2735
255	597	901	252	197	197	192	197	195	197	197	267	197	71	72	47	47	61	70	47	50	74	71	197	1152	180	50	5775	2835	3049	5884	2666	2990	5656	2767	2734
256	601	901	252	198	198	192	198	195	198	198	267	198	71	72	47	47	61	70	47	50	74	71	198	1152	180	50	5786	2835	3049	5884	2684	3012	5696	2785	2734
257	605	901	252	199	199	192	198	195	199	199	267	199	71	72	47	47	61	70	47	50	74	71	199	1152	180	50	5796	2835	3049	5884	2684	3020	5704	2803	2716
258	605	901	252	201	201	192	198	195	201	201	267	201	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5807	2835	3049	5884	2684	3020	5704	2821	2698
259	605	901	252	202	202	192	198	195	202	202	267	202	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5812	2835	3049	5884	2684	3020	5704	2839	2680
260	605	901	252	204	203	192	198	195	204	203	267	204	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5820	2835	3049	5884	2684	3020	5704	2857	2662
400	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5383	136
401	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5402	117
402	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5420	99
403	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5438	81
404	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5456	63
405	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5474	45
406	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5492	27
407	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5510	9
408	605	901	252	243	203	192	198	195	211	203	267	222	71	72	47	47	61	70	47	50	74	71	200	1152	180	50	5884	2835	3049	5884	2684	3020	5704	5519	0

Last ppl travel from stairway to outside on ground floor

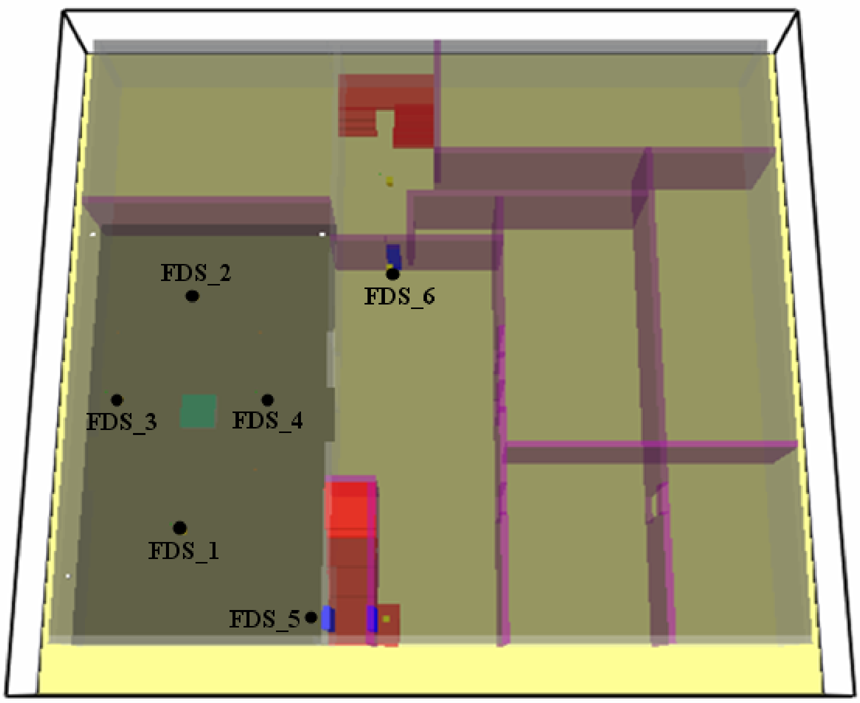
travel distance:	81	m
travel speed:	1.2	m/s
travel time:	68	s

time clear entire building to outside 476 s

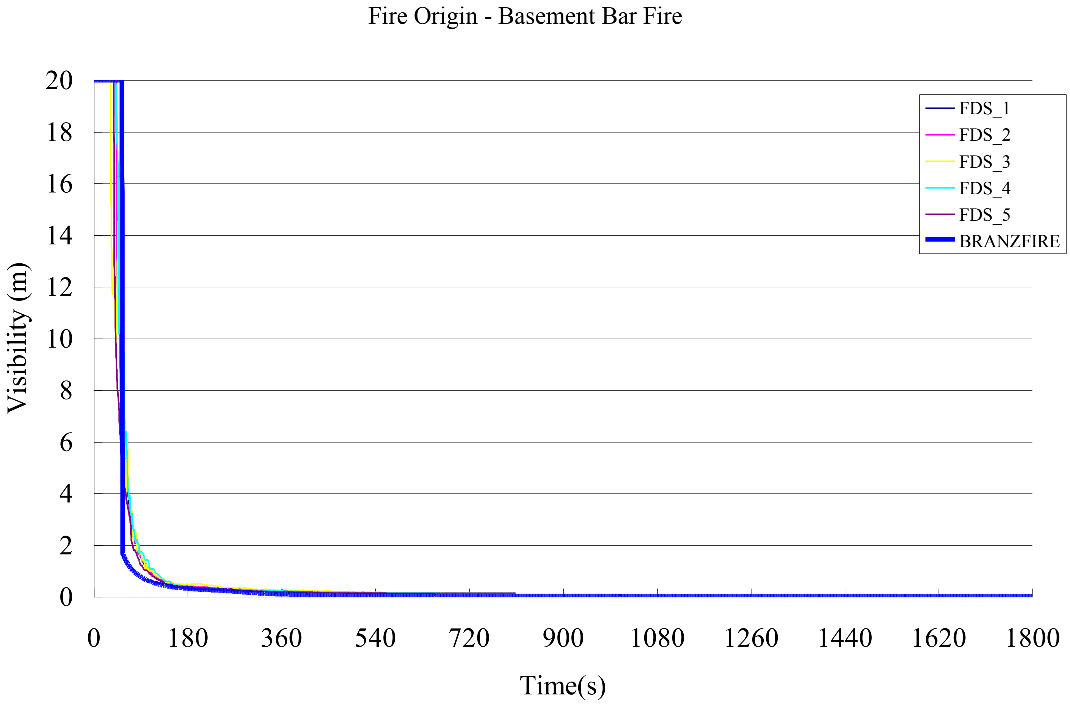
APPENDIX L FDS vs. BRANZFIRE

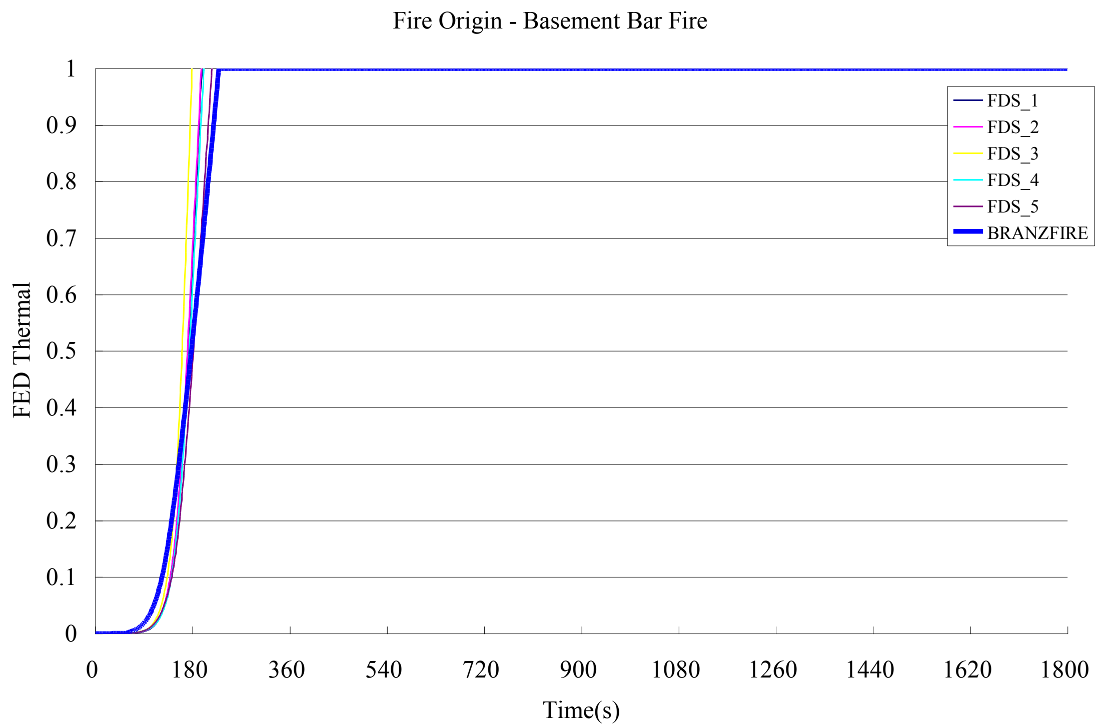
1. Nightclub – Basement Bar Fire

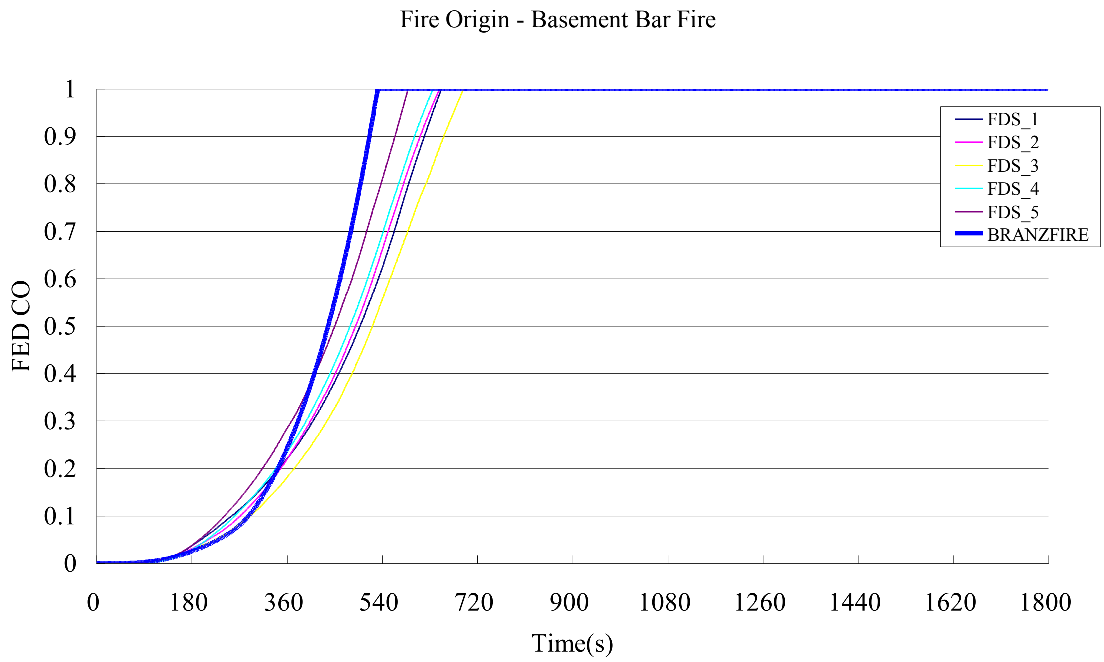
Devices location:



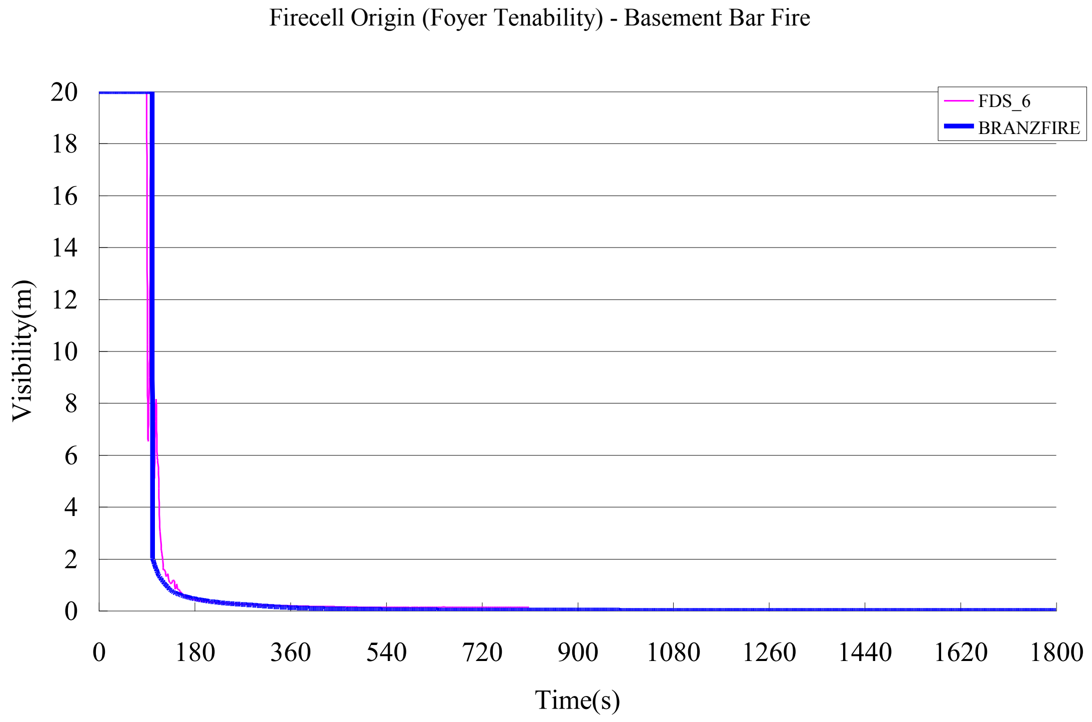
(1) Room of fire origin

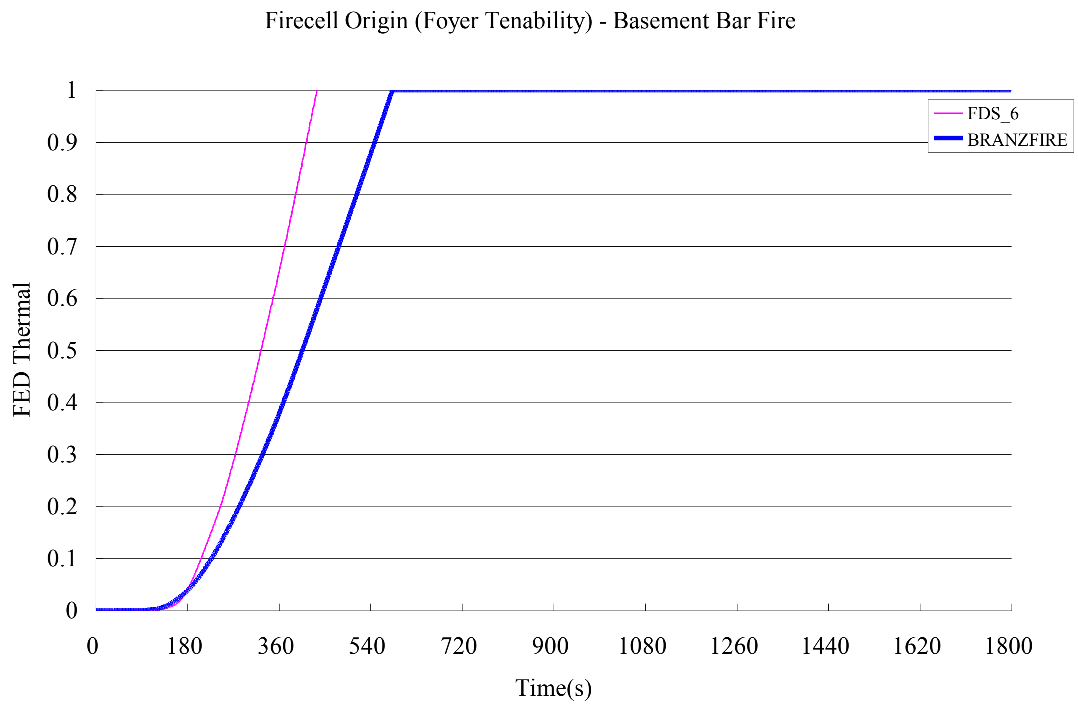


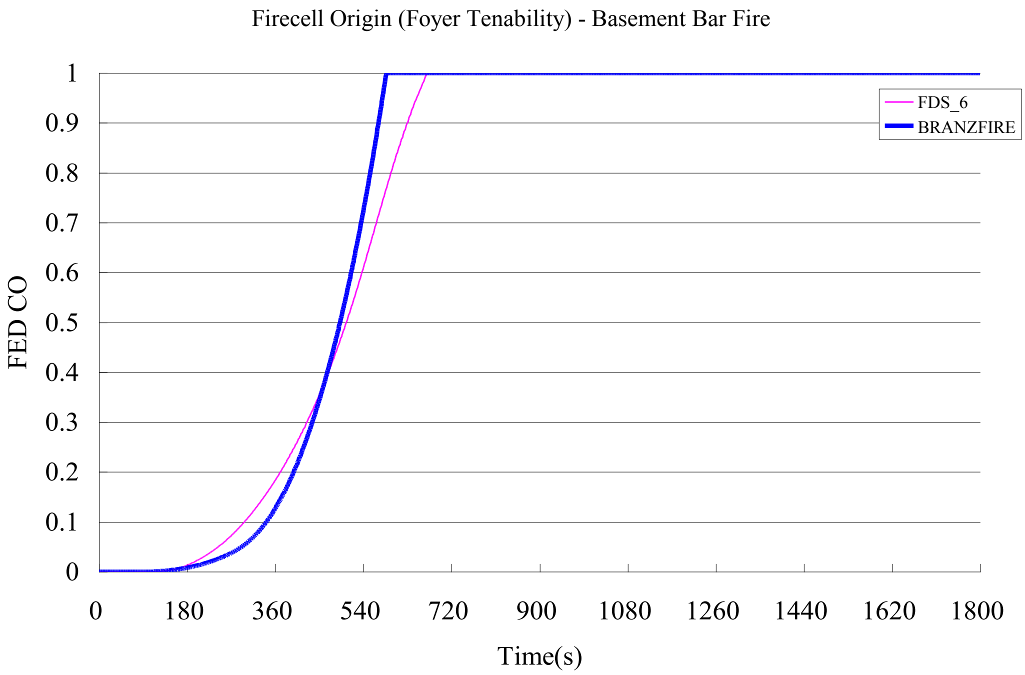

Fire Origin - Basement Bar Fire
FED Thermal
Time(s)
0
180
360
540
720
900
1080
1260
1440
1620
1800
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
BRANZFIRE


Fire Origin - Basement Bar Fire
FED CO
Time(s)
0
180
360
540
720
900
1080
1260
1440
1620
1800
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
BRANZFIRE

(2) Firecell of fire origin

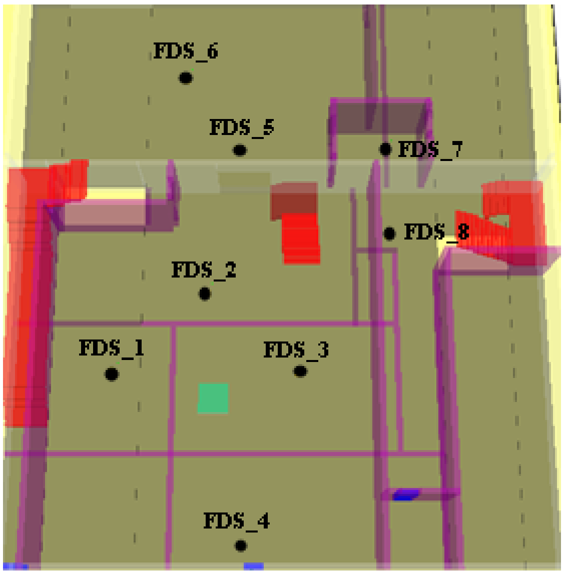




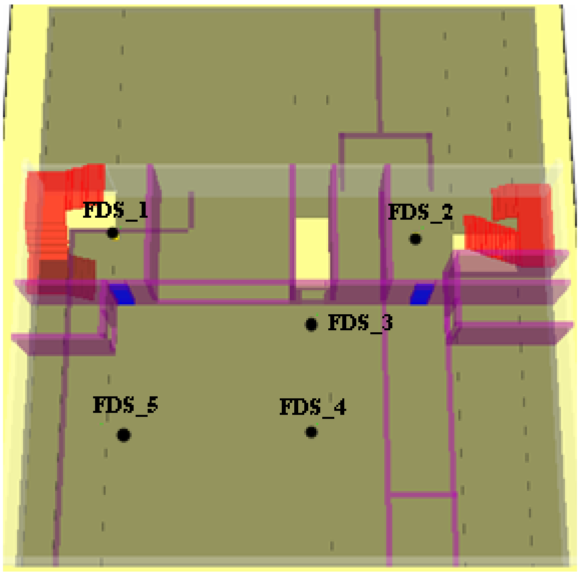


2. Nightclub – Ground Floor Dance Fire

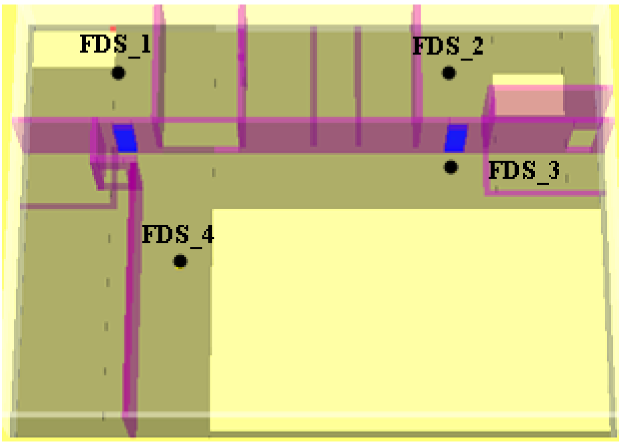
Device location:



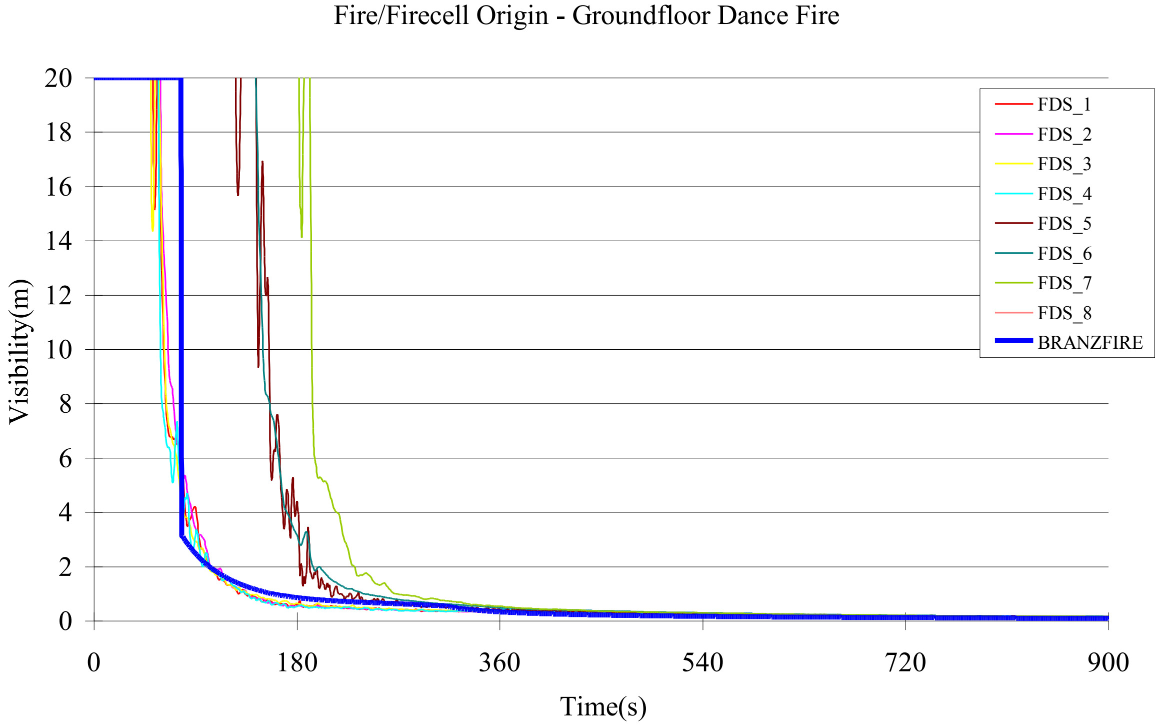
(Floor 1 – Ground floor)



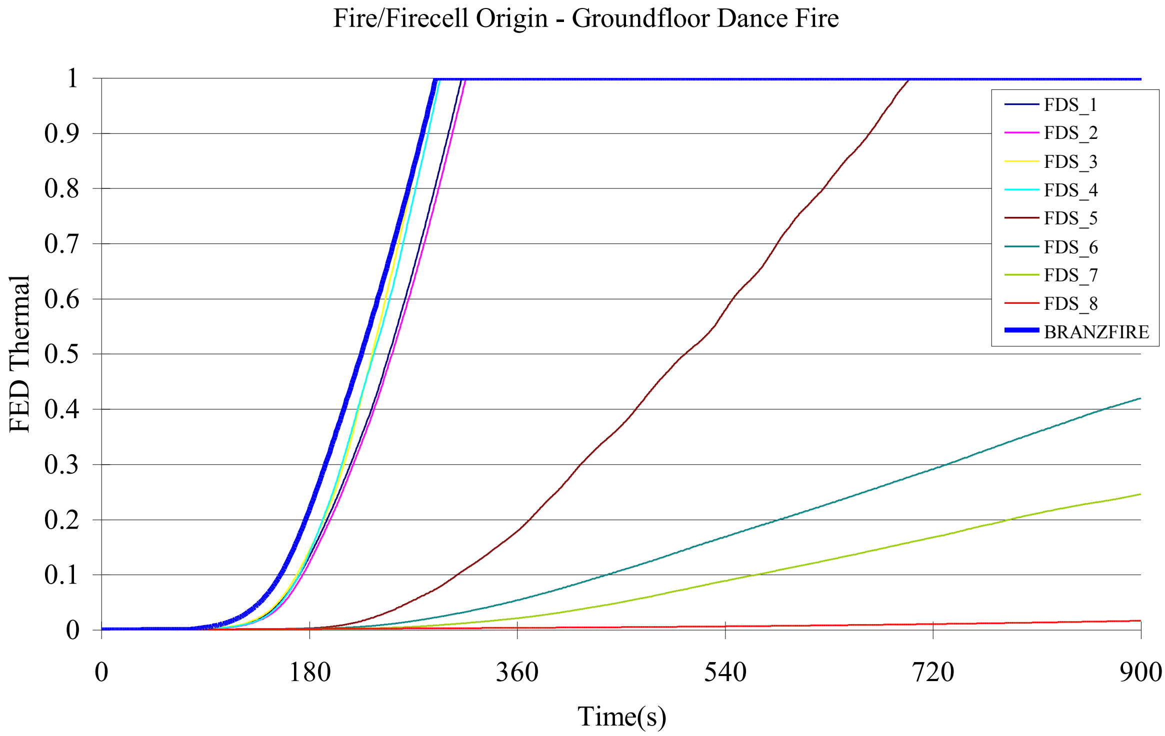
(Floor 2)



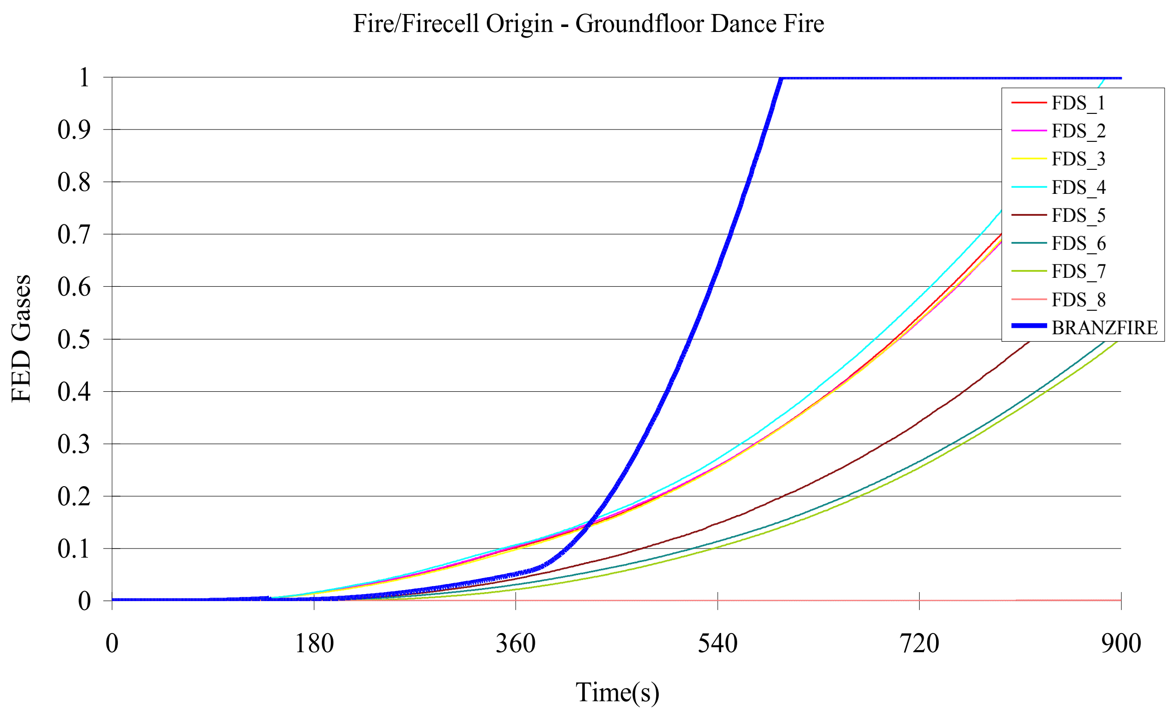
(Floor 3)

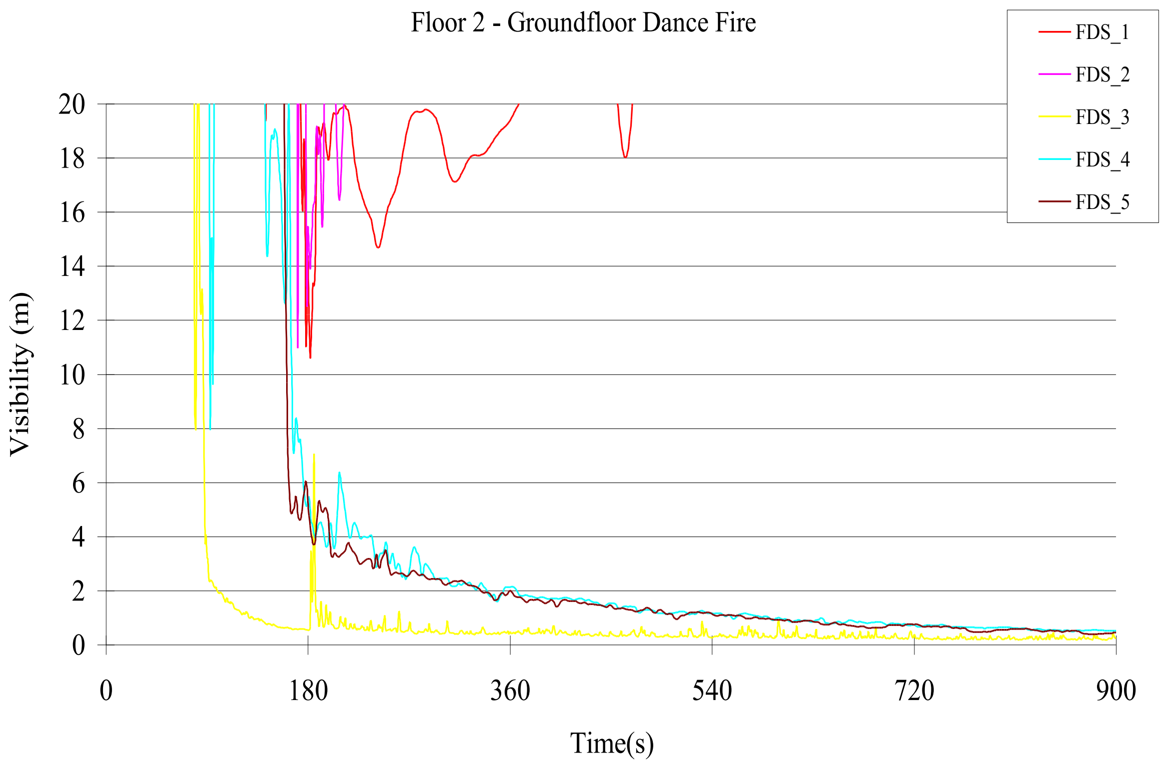


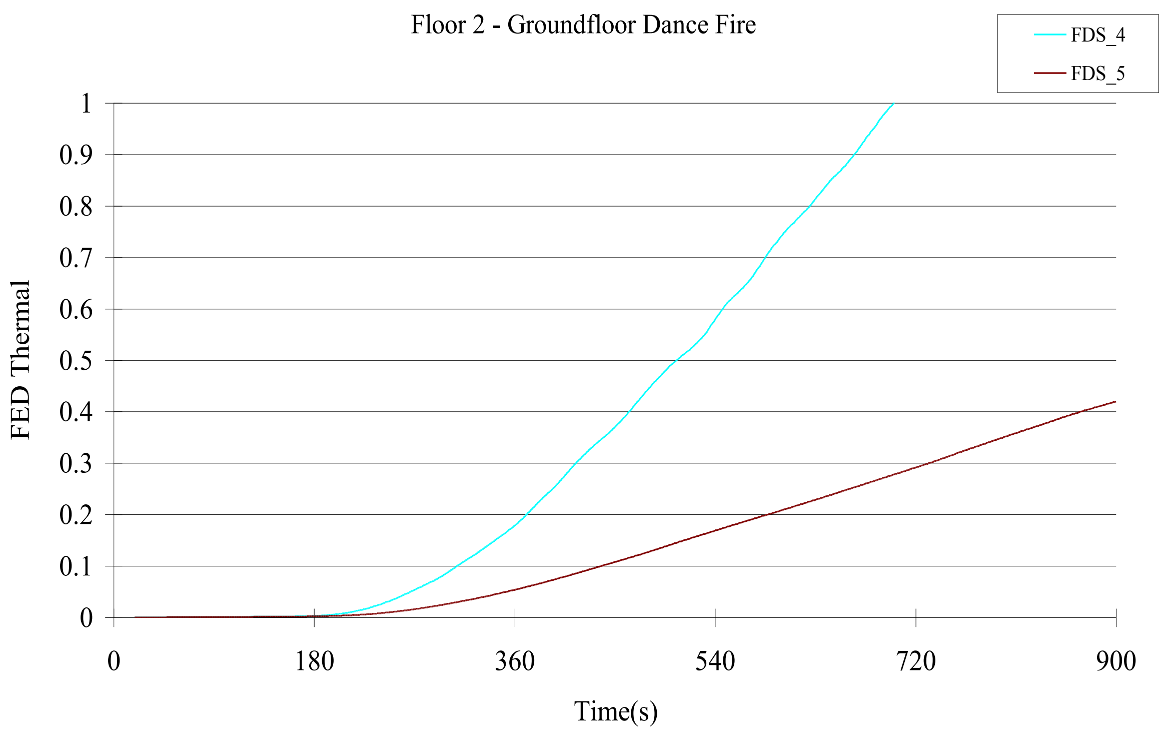
Fire/Firecell Origin - Groundfloor Dance Fire
Visibility(m)
Time(s)
0
2
4
6
8
10
12
14
16
18
20
0
180
360
540
720
900
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
FDS_7
FDS_8
BRANZFIRE



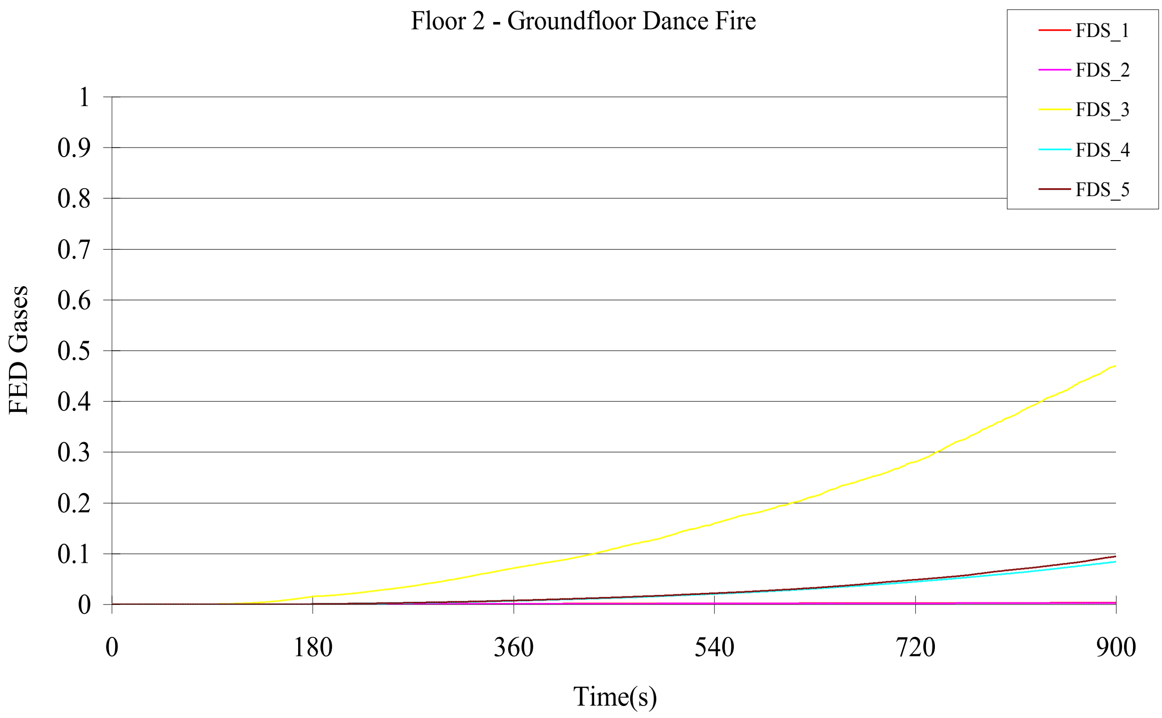
Fire/Firecell Origin - Groundfloor Dance Fire
FED Thermal
Time(s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
180
360
540
720
900
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
FDS_7
FDS_8
BRANZFIRE


Fire/Firecell Origin - Groundfloor Dance Fire
FED Gases
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
FDS_7
FDS_8
BRANZFIRE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
180
360
540
720
900

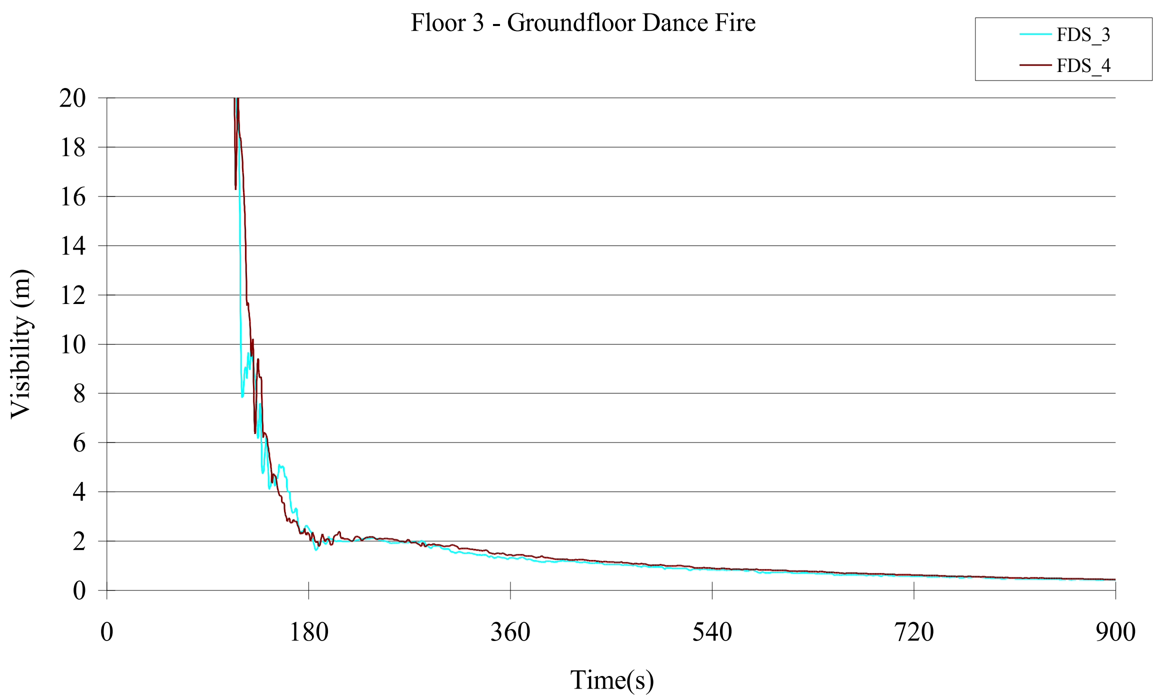

Floor 2 - Groundfloor Dance Fire
Visibility (m)
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
0
2
4
6
8
10
12
14
16
18
20
0
180
360
540
720
900



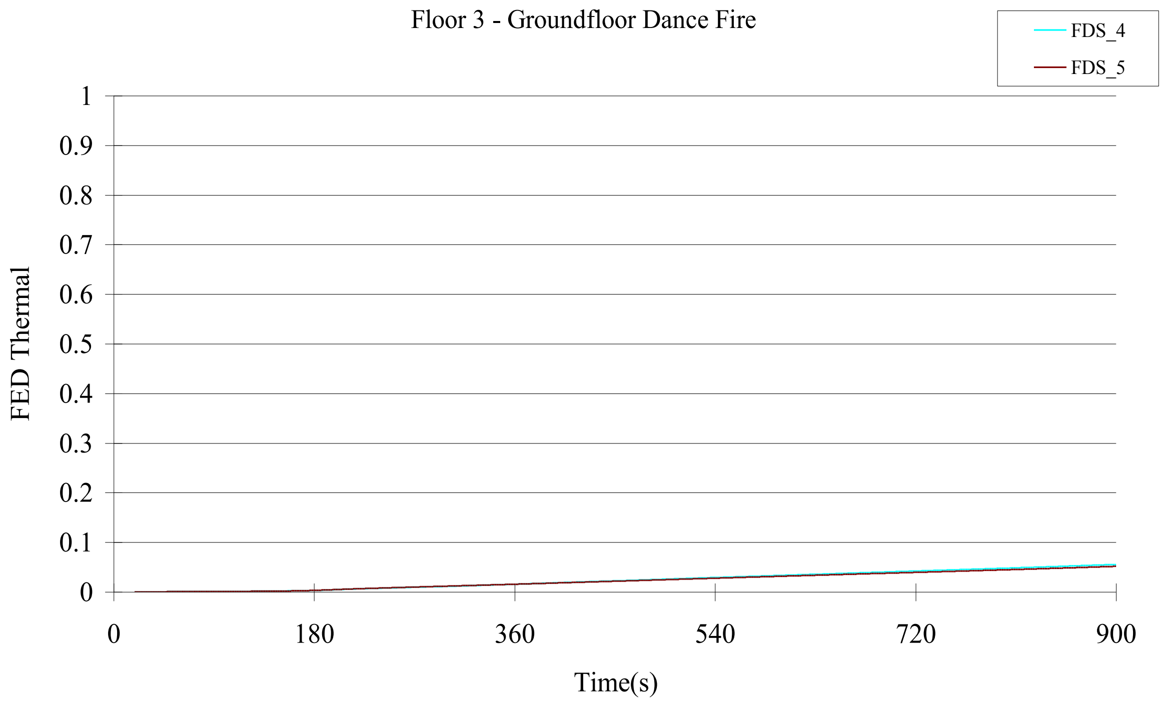
Floor 2 - Groundfloor Dance Fire
FDS_4
FDS_5
FED Thermal
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
Time(s)



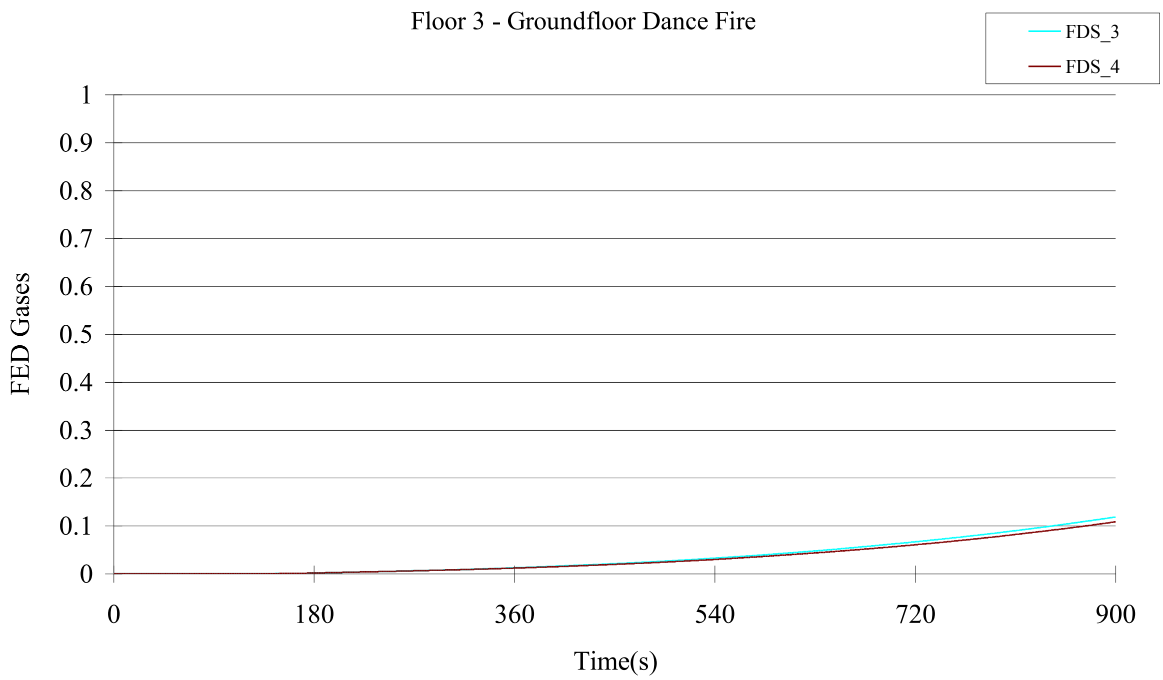
Floor 2 - Groundfloor Dance Fire
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FED Gases
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
Time(s)



Floor 3 - Groundfloor Dance Fire
FDS_3
FDS_4
Visibility (m)
20
18
16
14
12
10
8
6
4
2
0
0
180
360
540
720
900
Time(s)

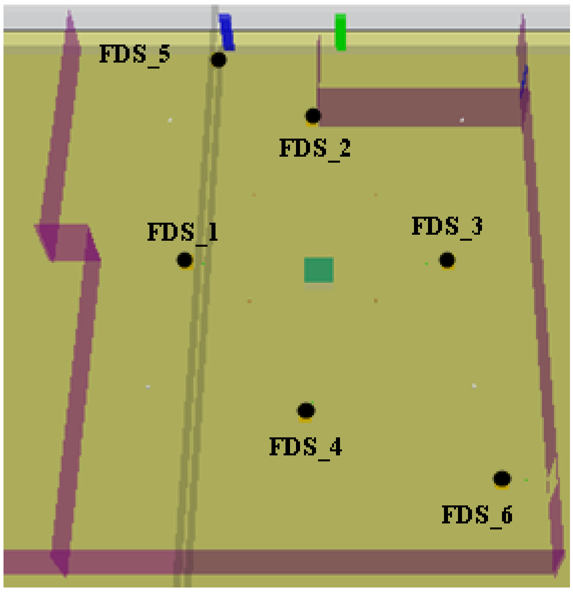


Floor 3 - Groundfloor Dance Fire
FDS_4
FDS_5
FED Thermal
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
Time(s)

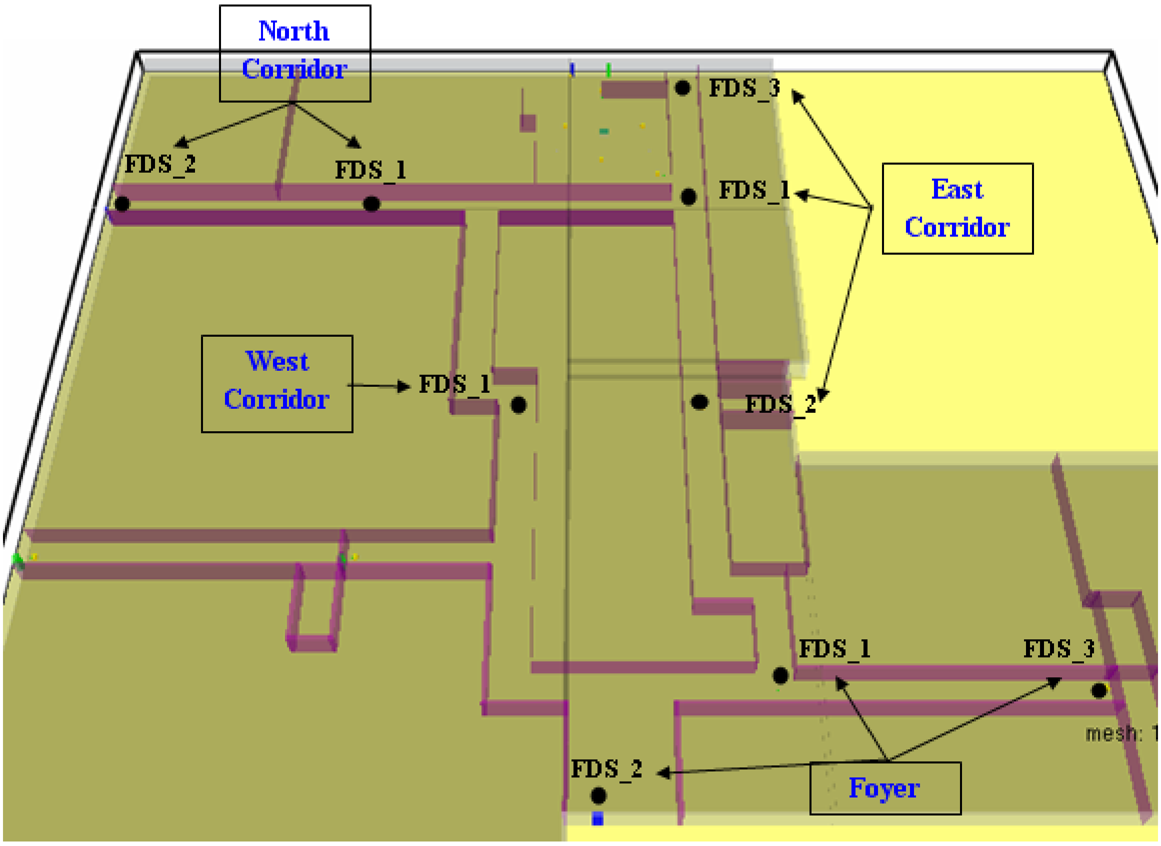


3. Hospital – Cafeteria Fire

Device location:



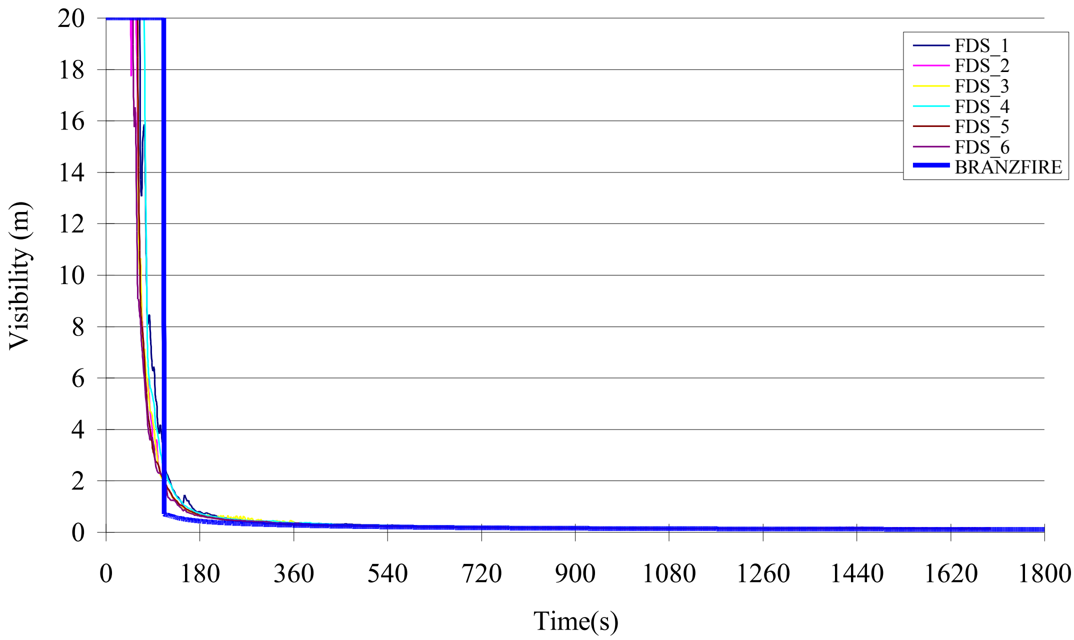
(Fire origin – Cafeteria)

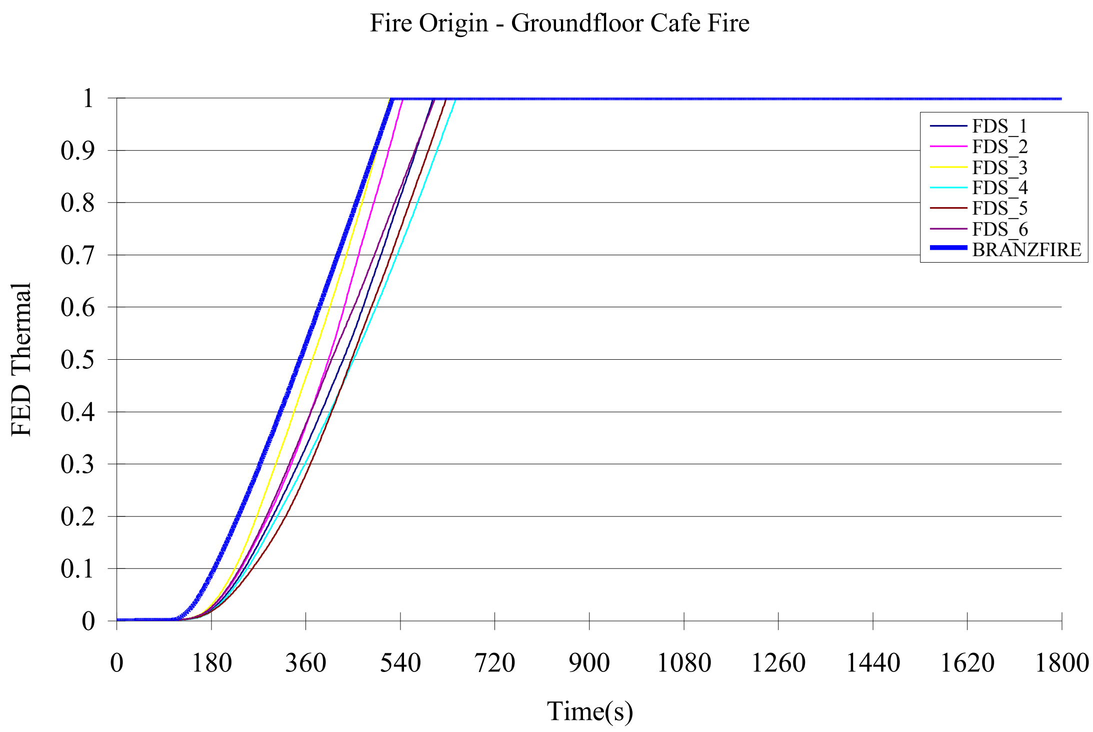


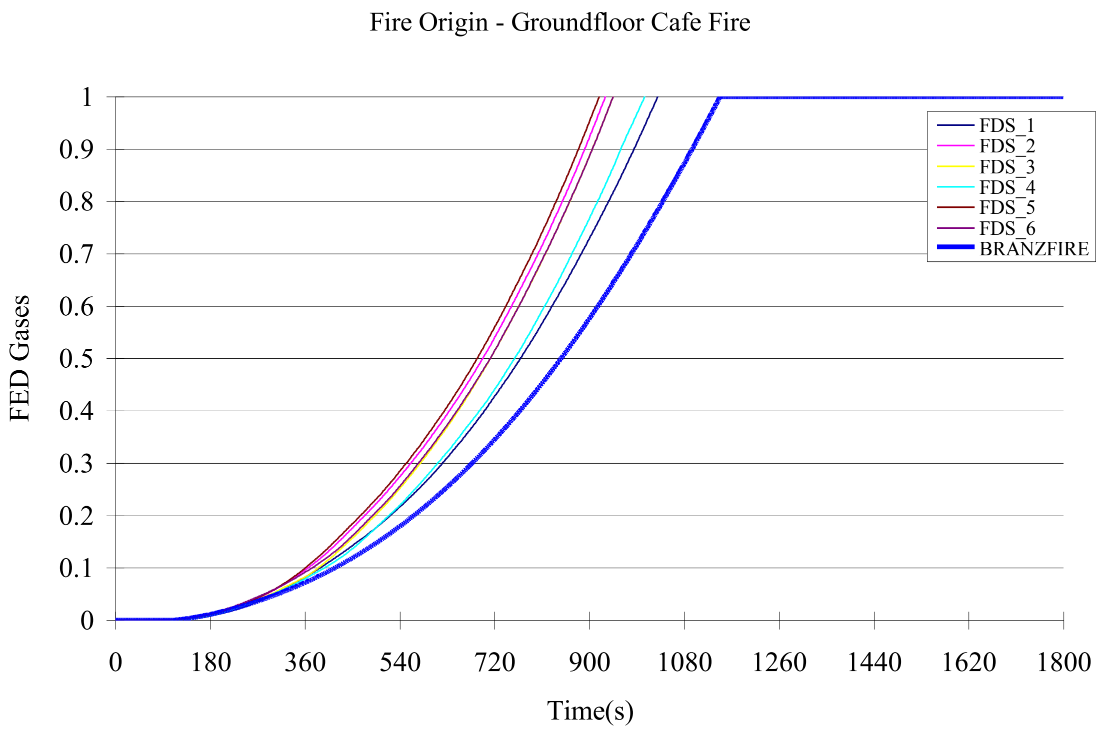
(Corridors)

(1) Room of fire origin

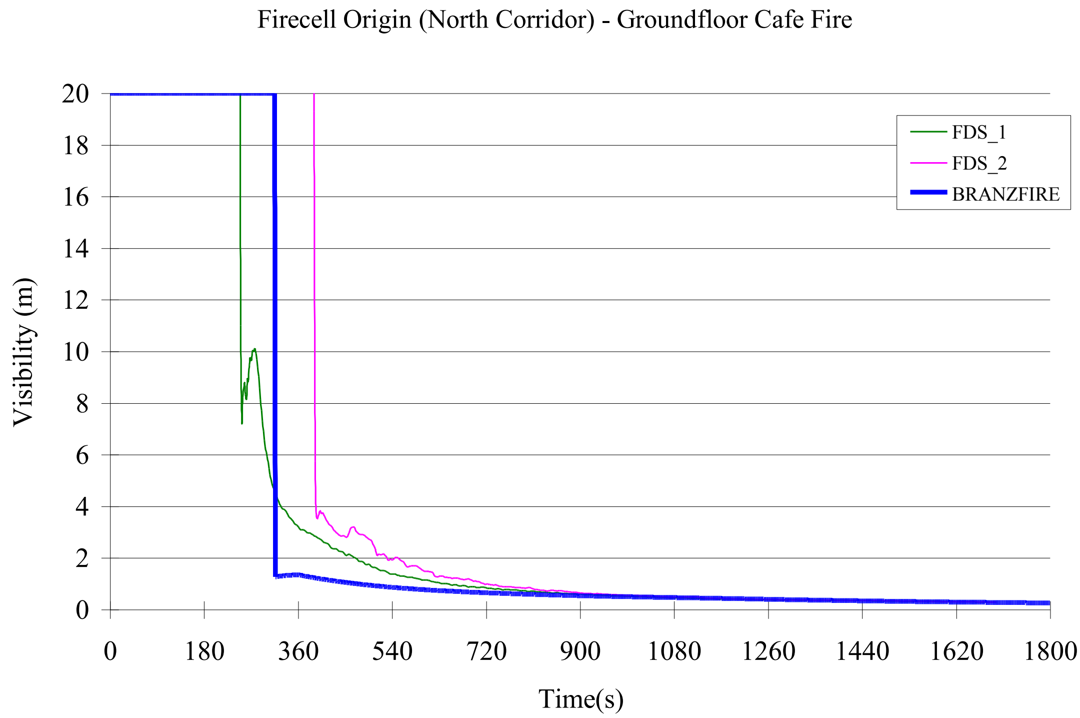
Fire Origin - Groundfloor Cafe Fire

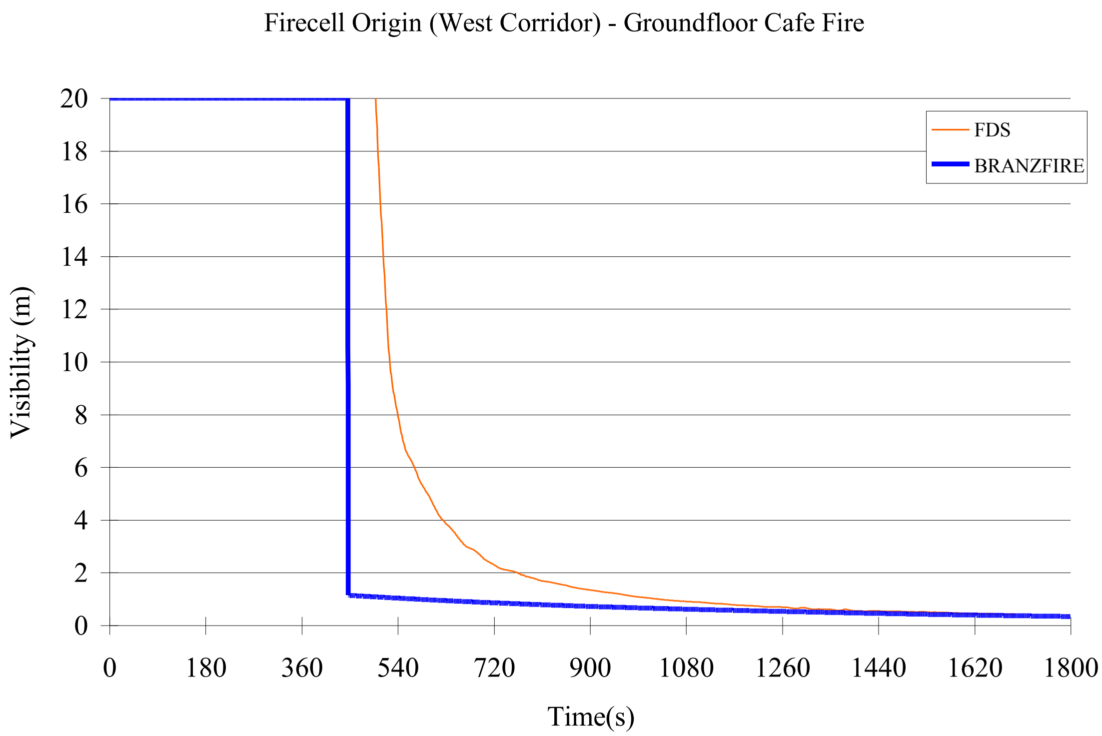


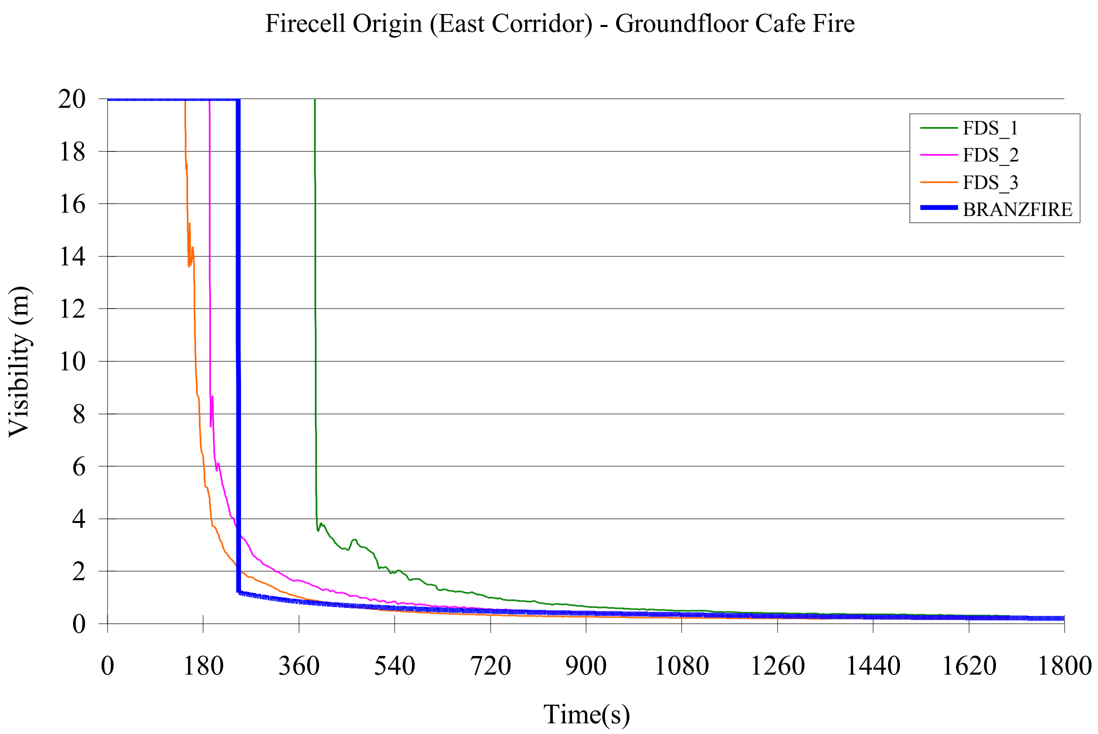

Fire Origin - Groundfloor Cafe Fire
FED Thermal
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 180 360 540 720 900 1080 1260 1440 1620 1800
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
BRANZFIRE

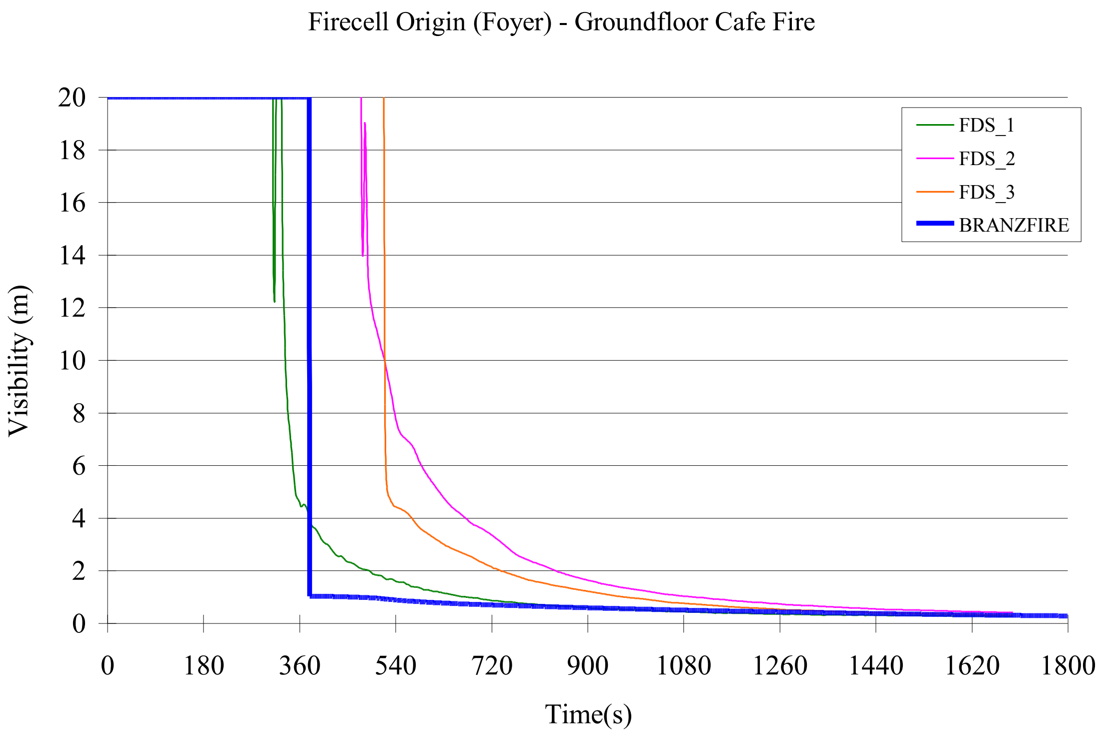

Fire Origin - Groundfloor Cafe Fire
FED Gases
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 180 360 540 720 900 1080 1260 1440 1620 1800
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
BRANZFIRE

(2) Firecell of fire origin

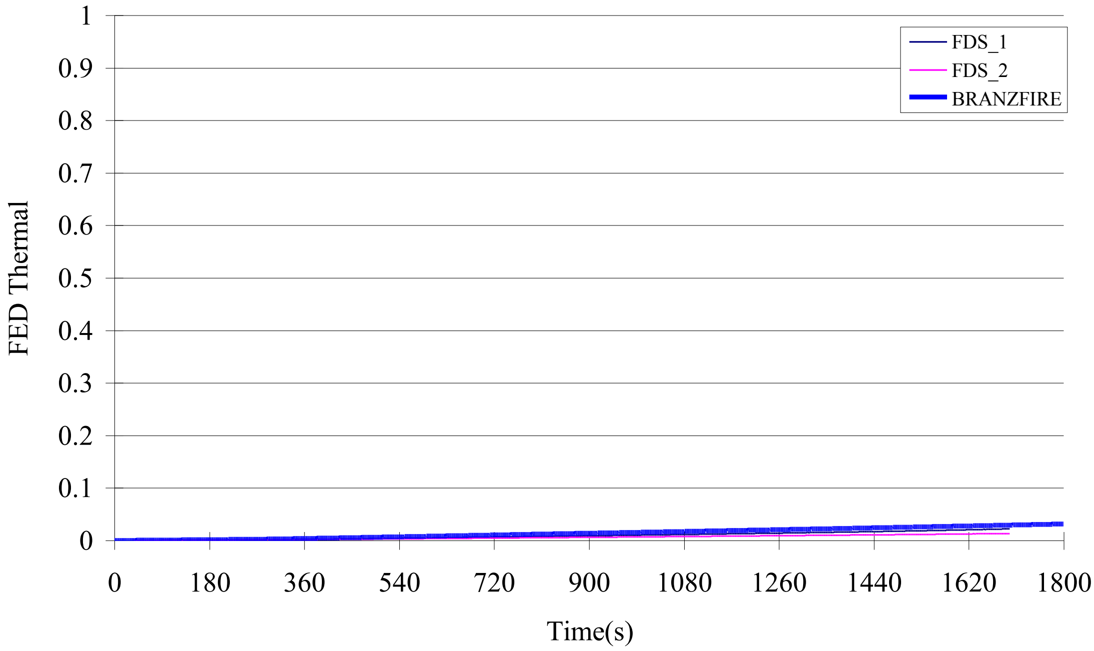




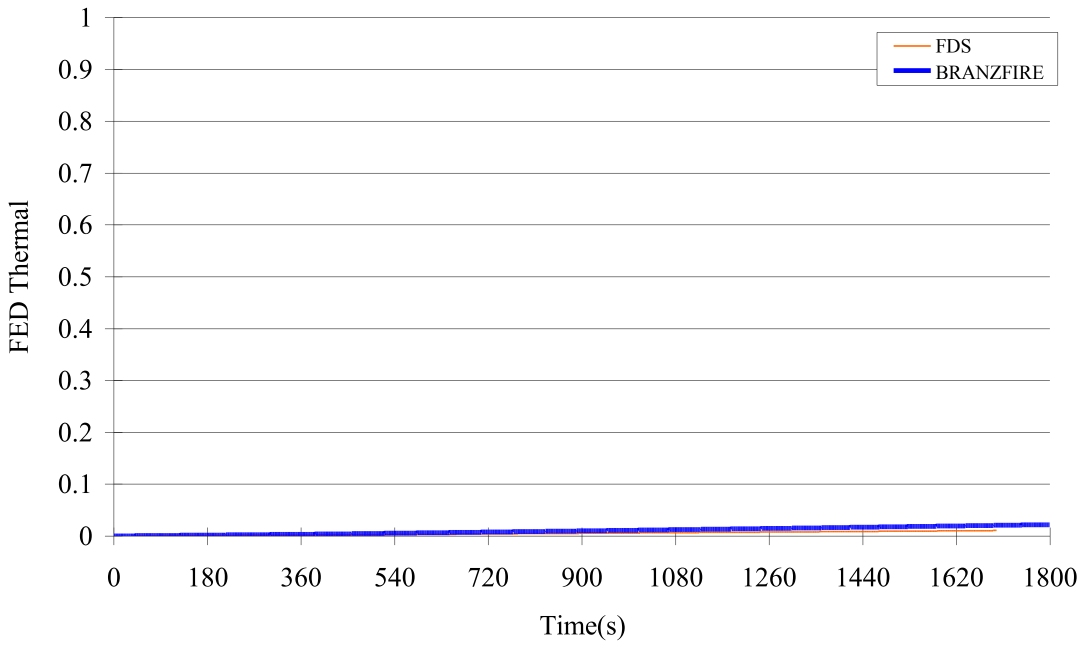

Firecell Origin (East Corridor) - Groundfloor Cafe Fire
Visibility (m)
Time(s)
FDS_1
FDS_2
FDS_3
BRANZFIRE
0
2
4
6
8
10
12
14
16
18
20
0
180
360
540
720
900
1080
1260
1440
1620
1800

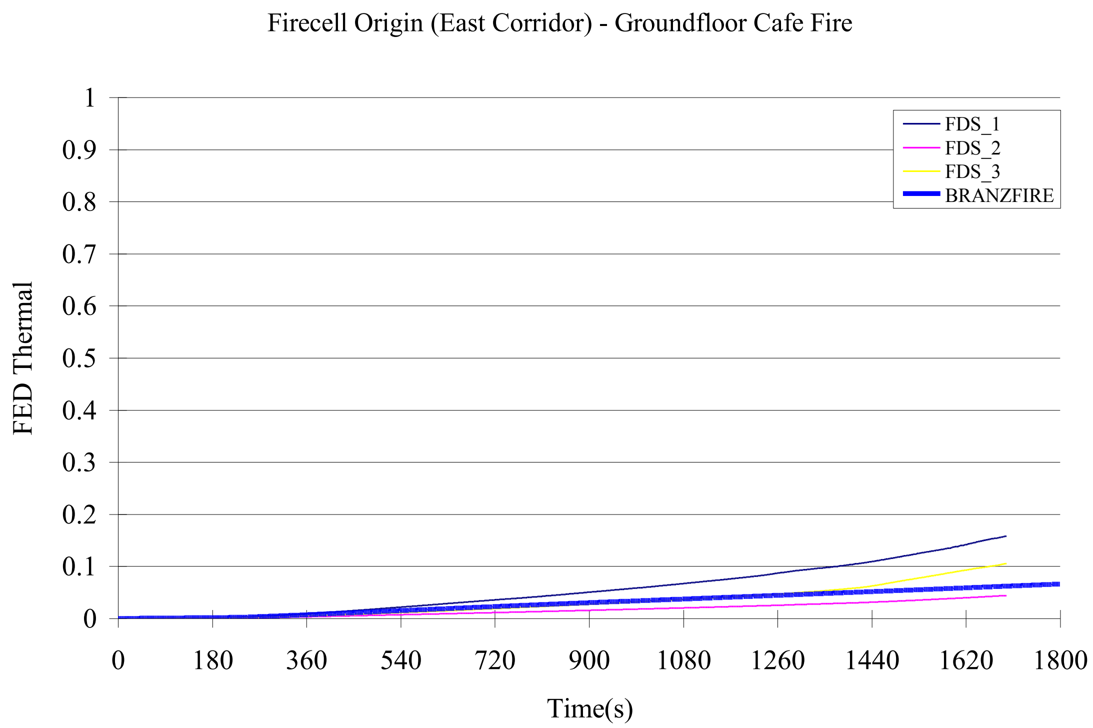

Firecell Origin (Foyer) - Groundfloor Cafe Fire
Visibility (m)
Time(s)
FDS_1
FDS_2
FDS_3
BRANZFIRE
0
2
4
6
8
10
12
14
16
18
20
0
180
360
540
720
900
1080
1260
1440
1620
1800

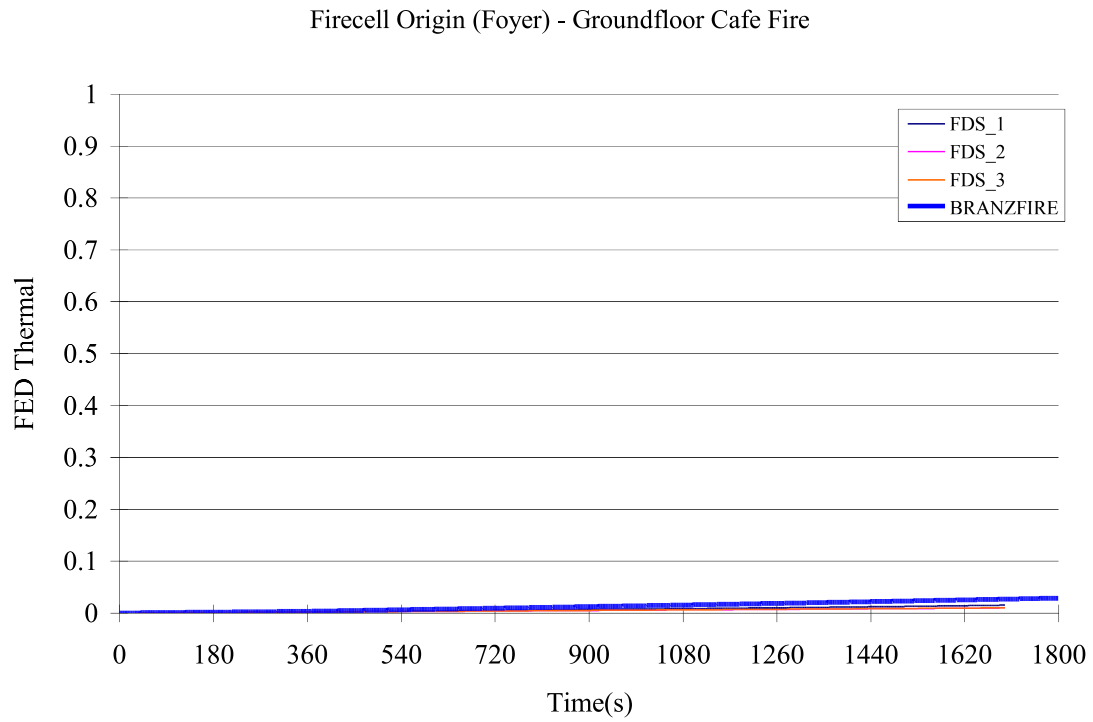
Firecell Origin (North Corridor) - Groundfloor Cafe Fire

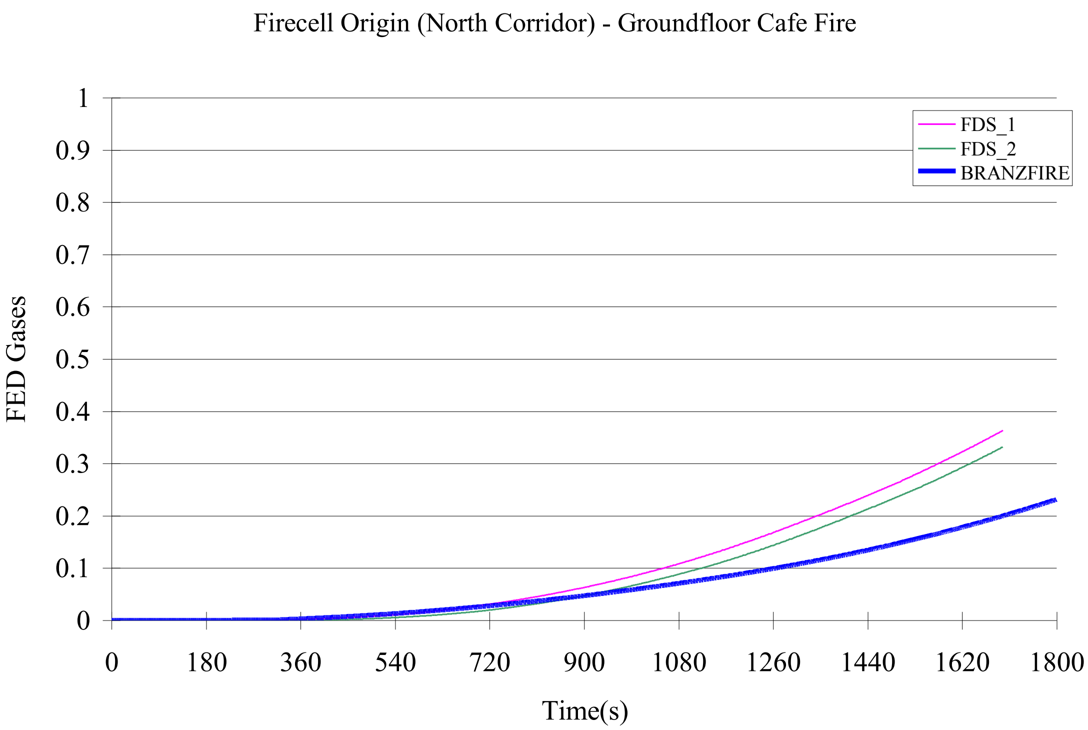


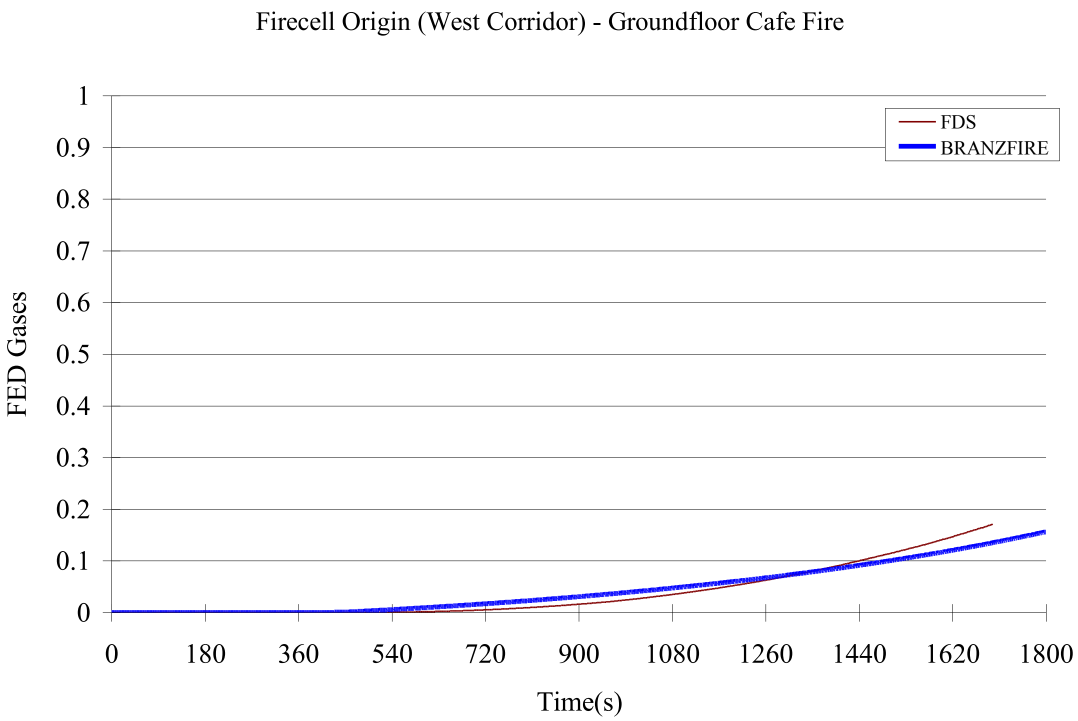
Firecell Origin (West Corridor) - Groundfloor Cafe Fire

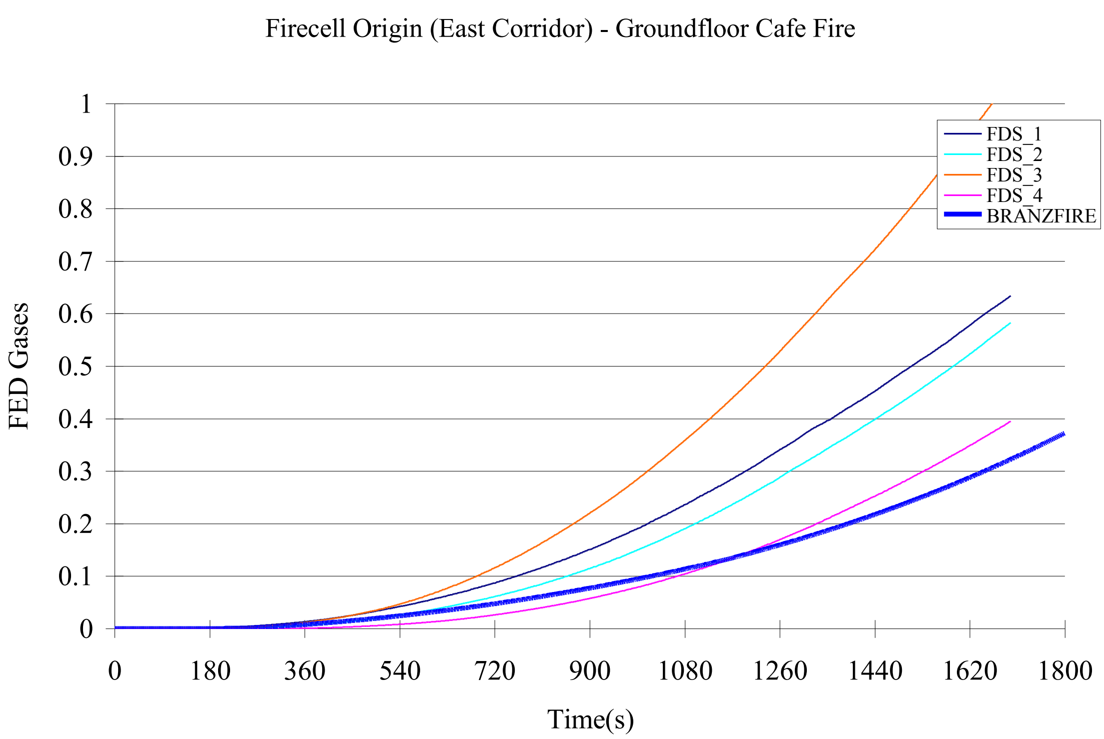



Firecell Origin (East Corridor) - Groundfloor Cafe Fire
FED Thermal
Time(s)
FDS_1
FDS_2
FDS_3
BRANZFIRE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
180
360
540
720
900
1080
1260
1440
1620
1800

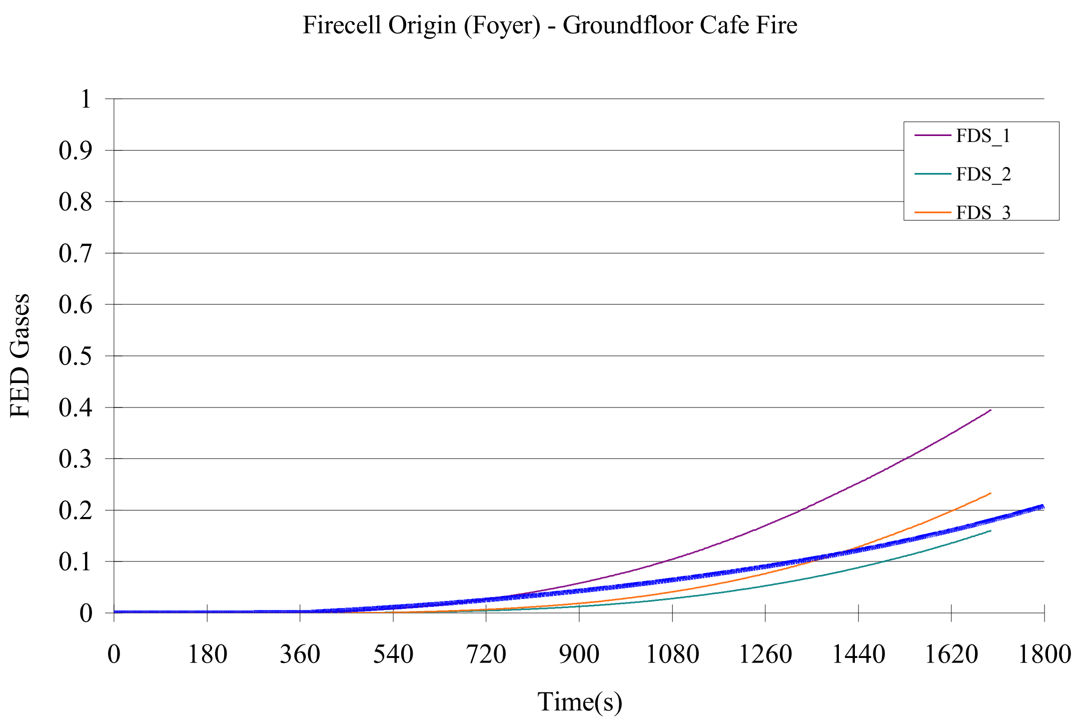

Firecell Origin (Foyer) - Groundfloor Cafe Fire
FED Thermal
Time(s)
FDS_1
FDS_2
FDS_3
BRANZFIRE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
180
360
540
720
900
1080
1260
1440
1620
1800


Firecell Origin (North Corridor) - Groundfloor Cafe Fire
FDS_1
FDS_2
BRANZFIRE
FED Gases
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
1080
1260
1440
1620
1800
Time(s)


Firecell Origin (West Corridor) - Groundfloor Cafe Fire
FDS
BRANZFIRE
FED Gases
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
1080
1260
1440
1620
1800
Time(s)



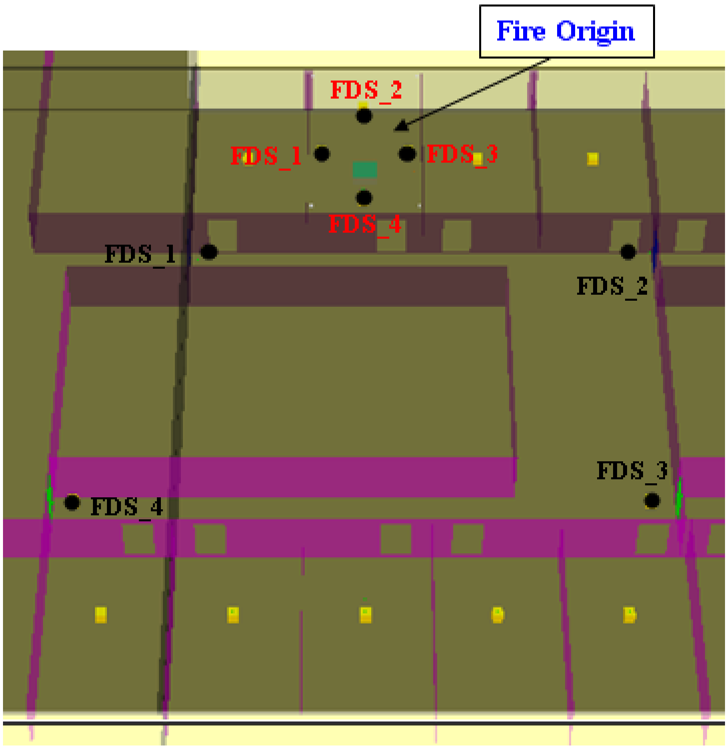
Firecell Origin (East Corridor) - Groundfloor Cafe Fire
FDS Gases
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
BRANZFIRE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
180
360
540
720
900
1080
1260
1440
1620
1800



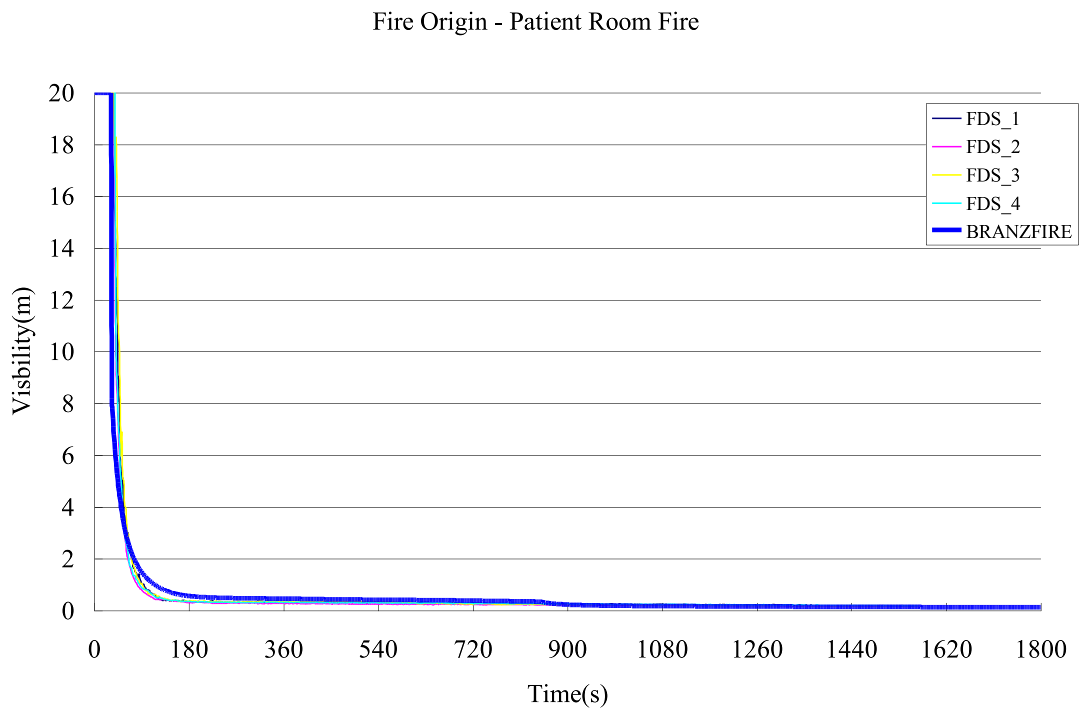
Firecell Origin (Foyer) - Groundfloor Cafe Fire
FED Gases
Time(s)
FDS_1
FDS_2
FDS_3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
180
360
540
720
900
1080
1260
1440
1620
1800

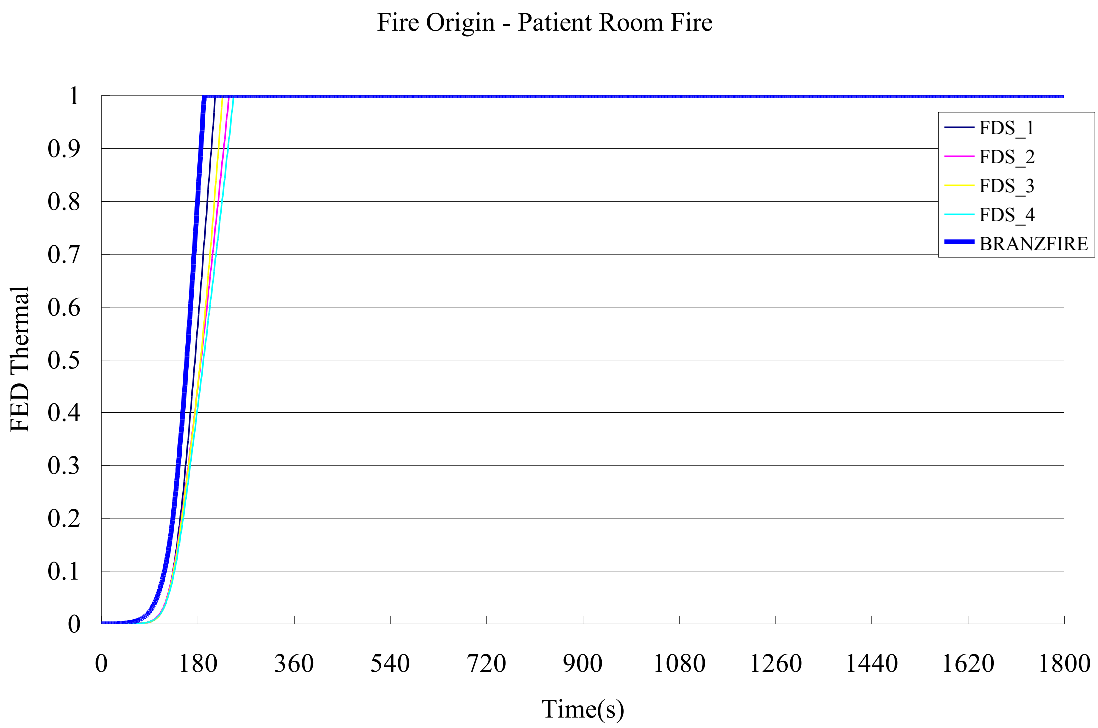
4. Hospital – Patient Room Fire (with compartmentation)

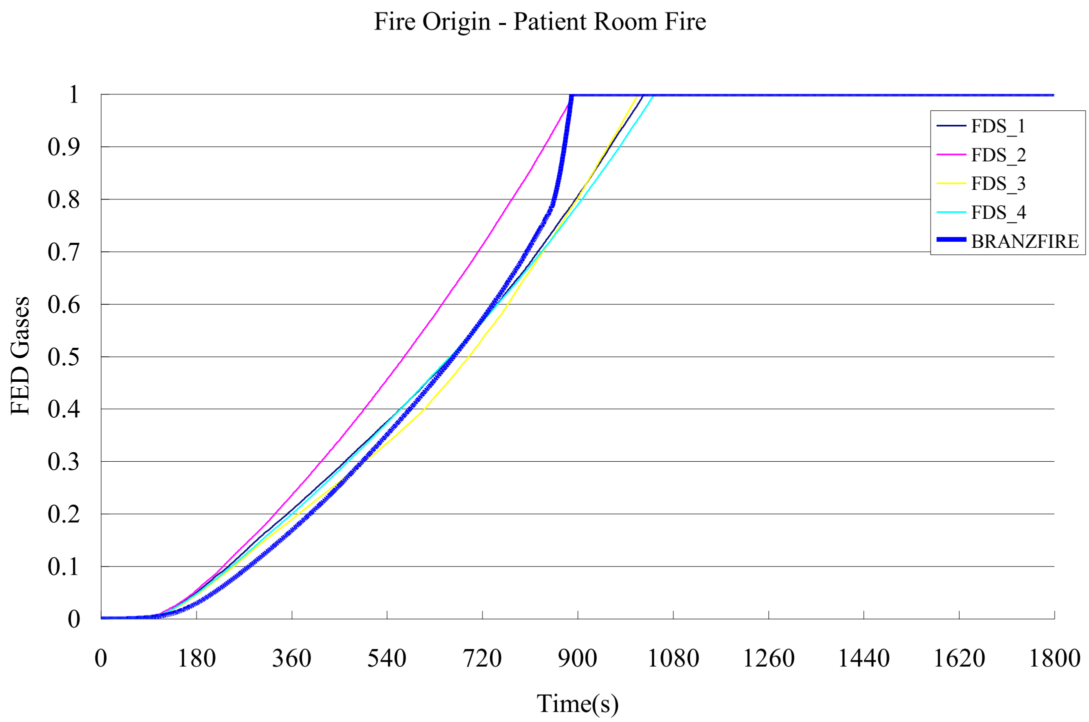
Device location:



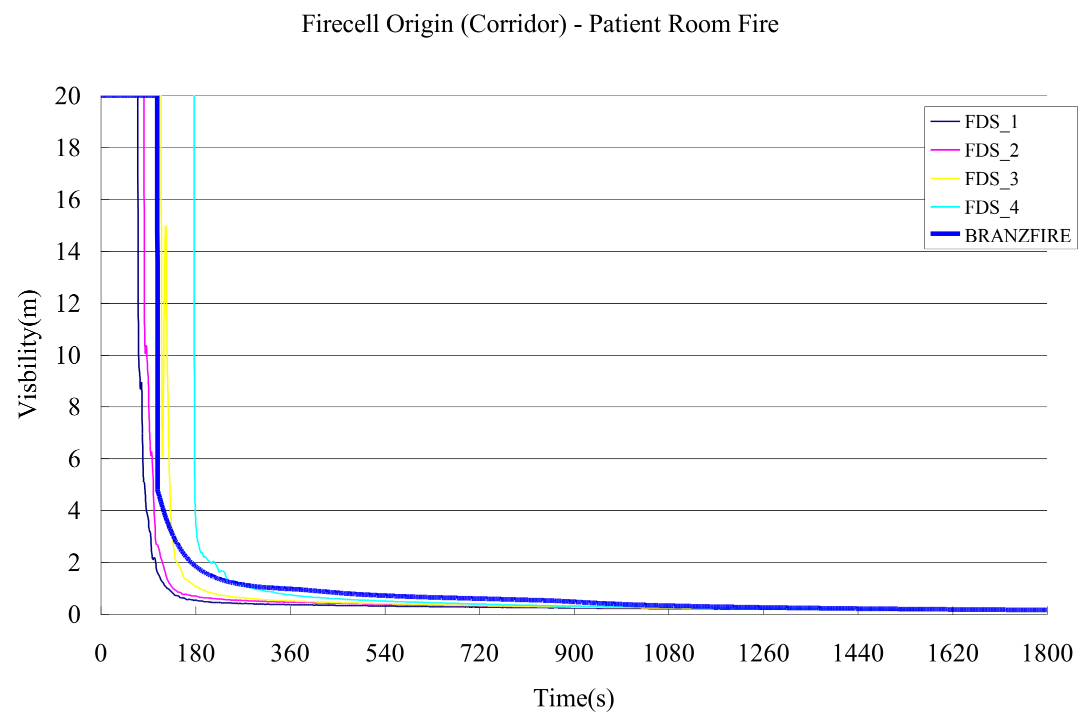
(1) Room of fire origin

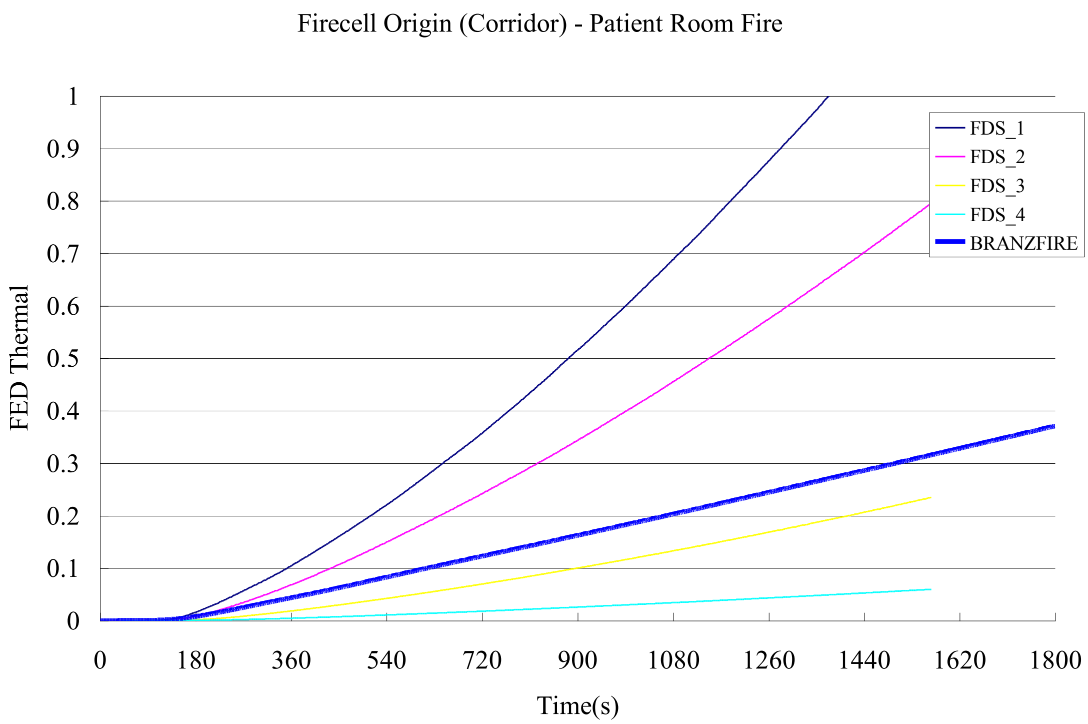


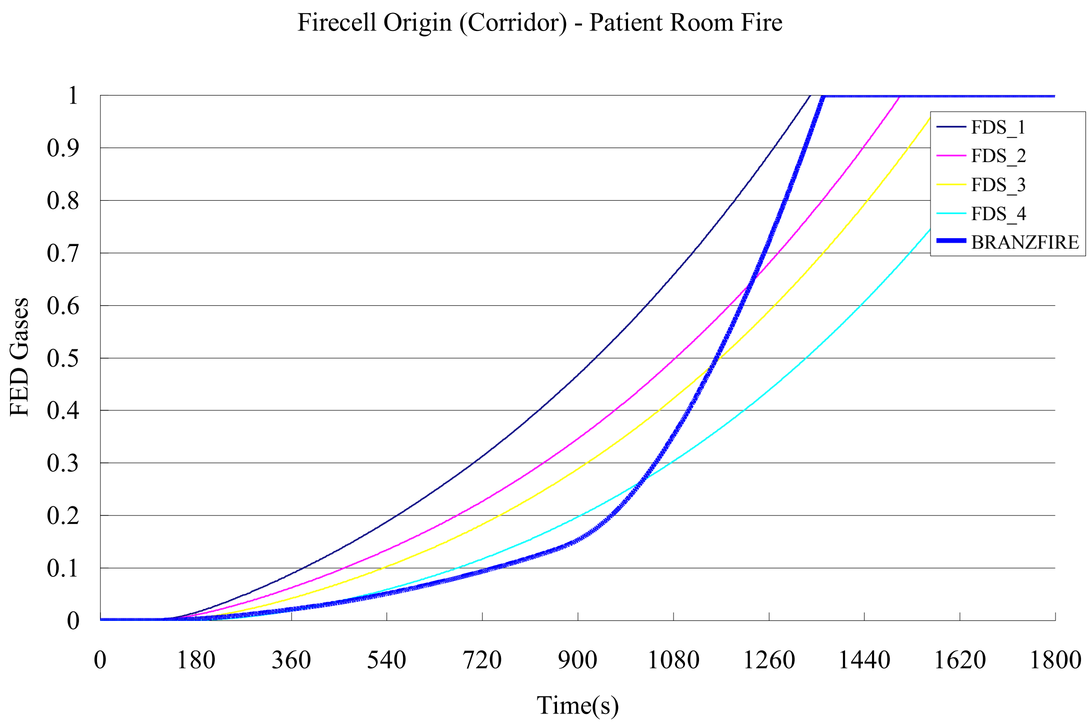

Fire Origin - Patient Room Fire
FED Thermal
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
1080
1260
1440
1620
1800
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
BRANZFIRE


Fire Origin - Patient Room Fire
FED Gases
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
1080
1260
1440
1620
1800
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
BRANZFIRE

(2) Firecell of fire origin

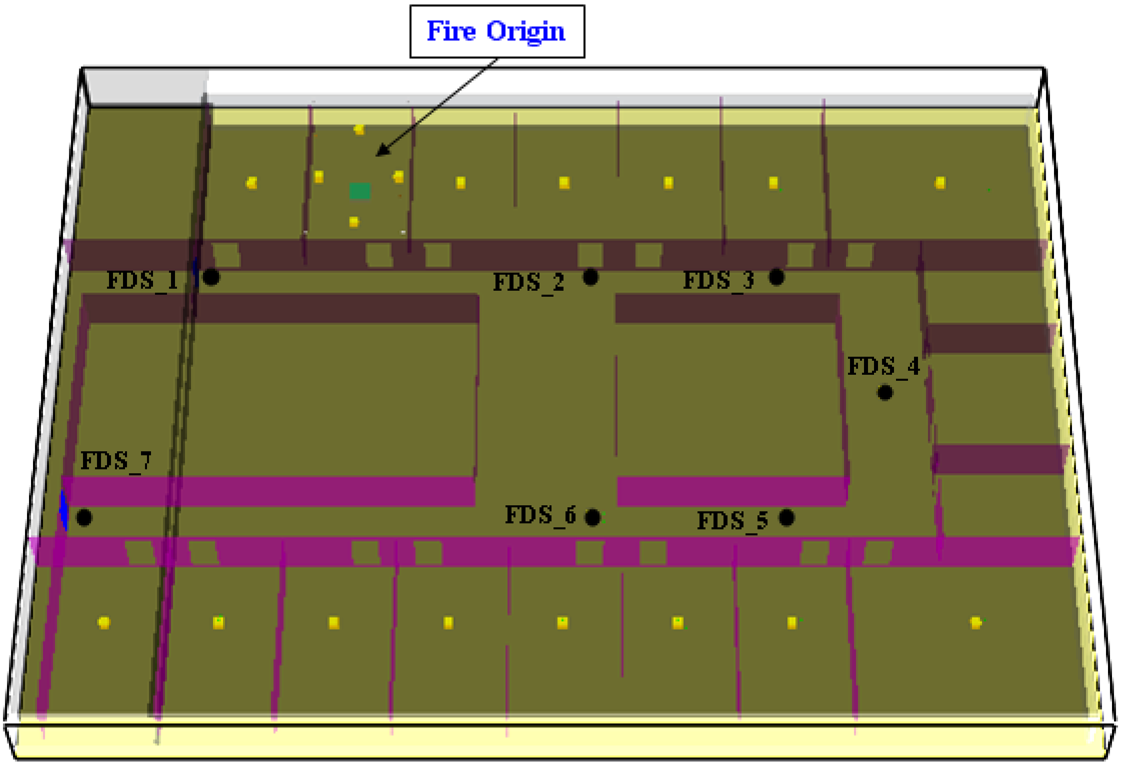




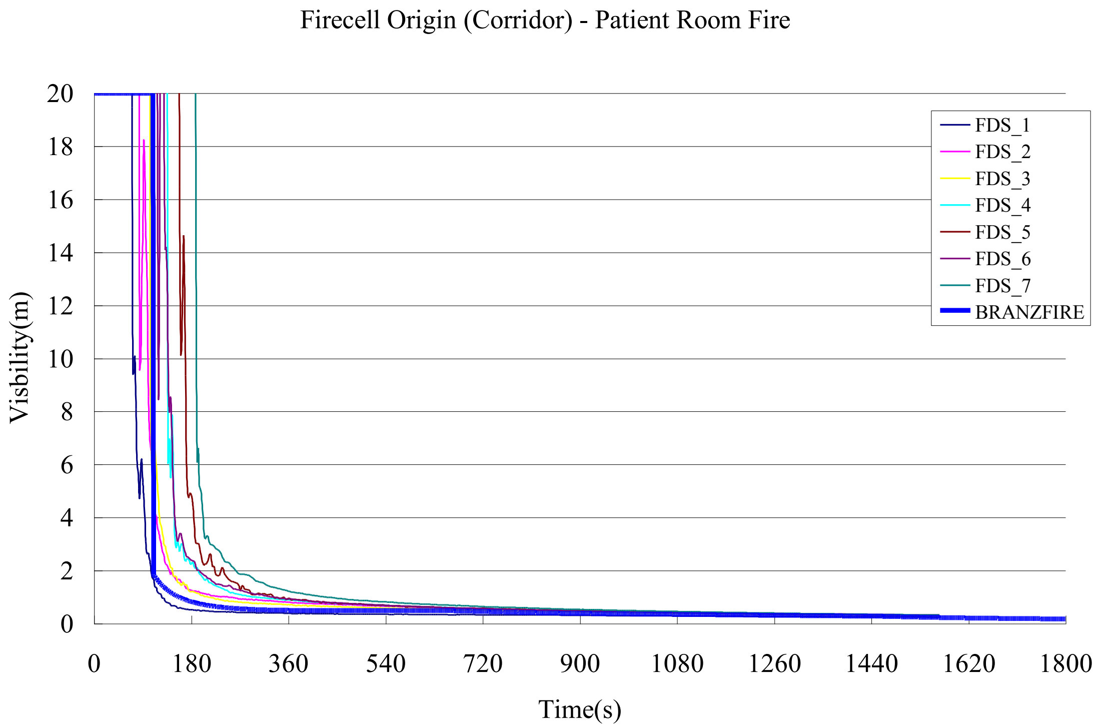


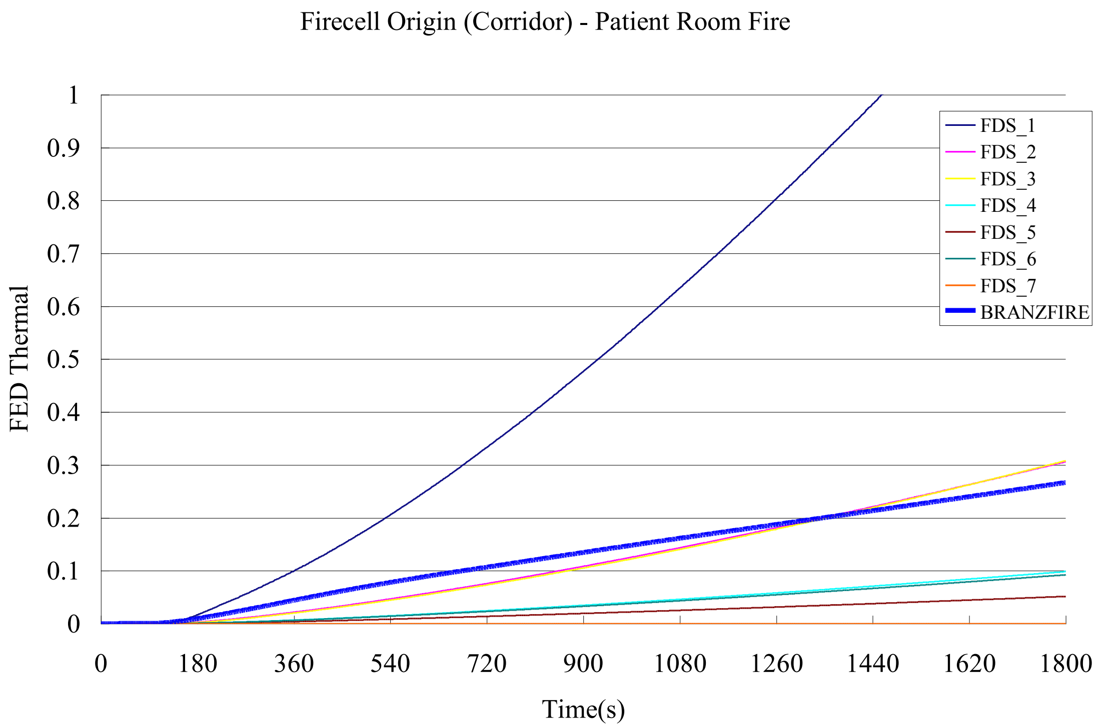
5. Hospital – Patient Room Fire (without compartmentation)

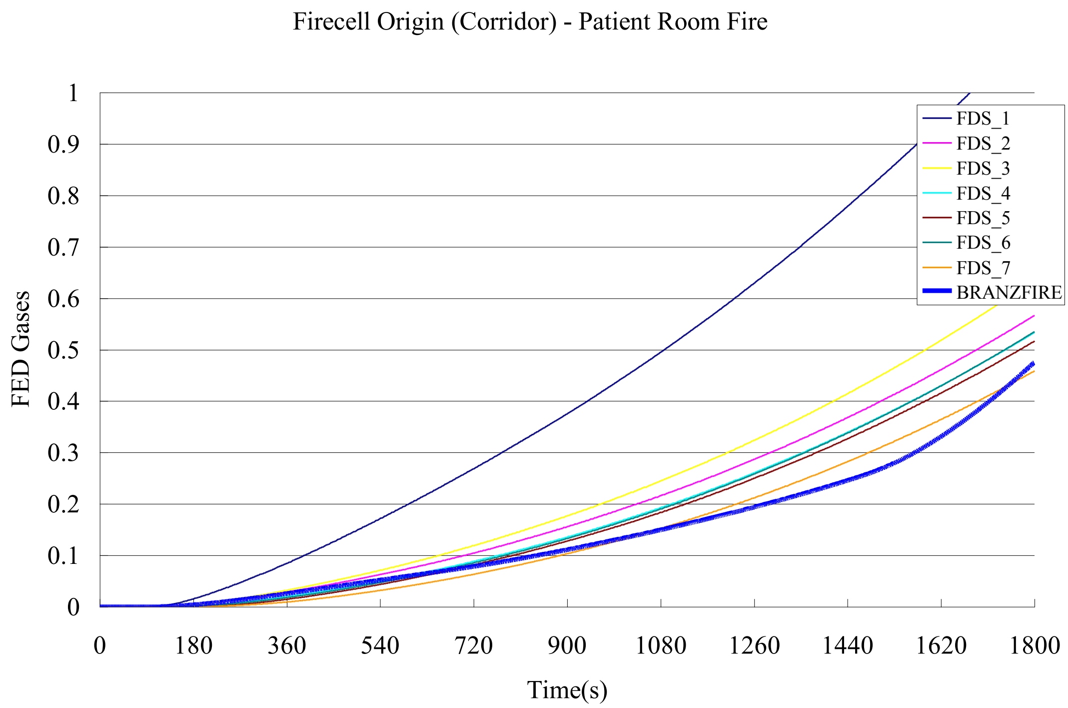
Device location:



(1) Firecell of fire origin

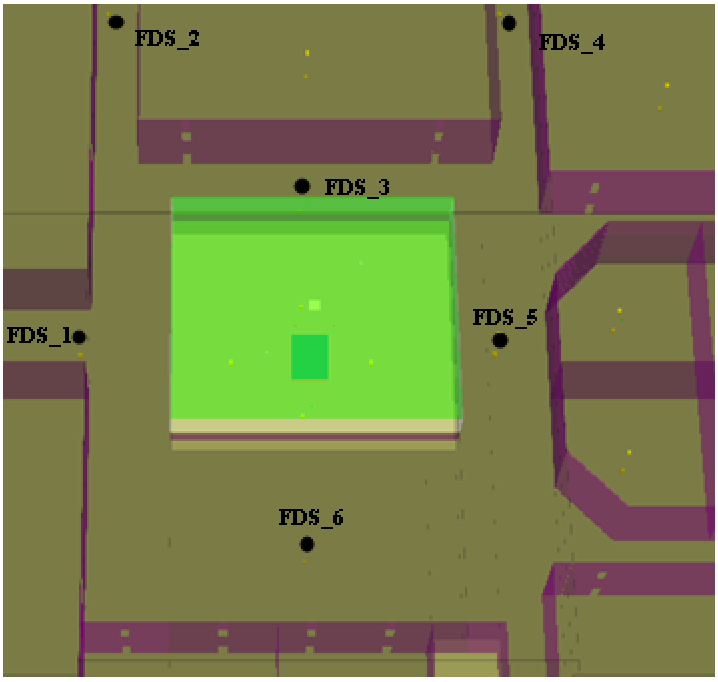


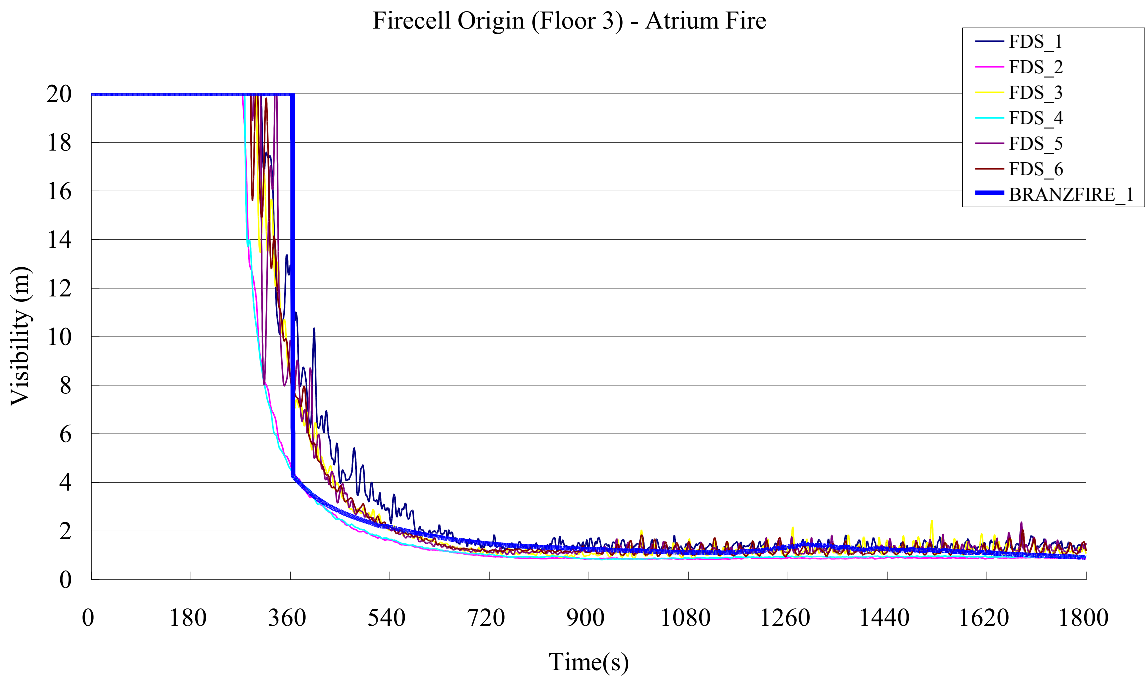




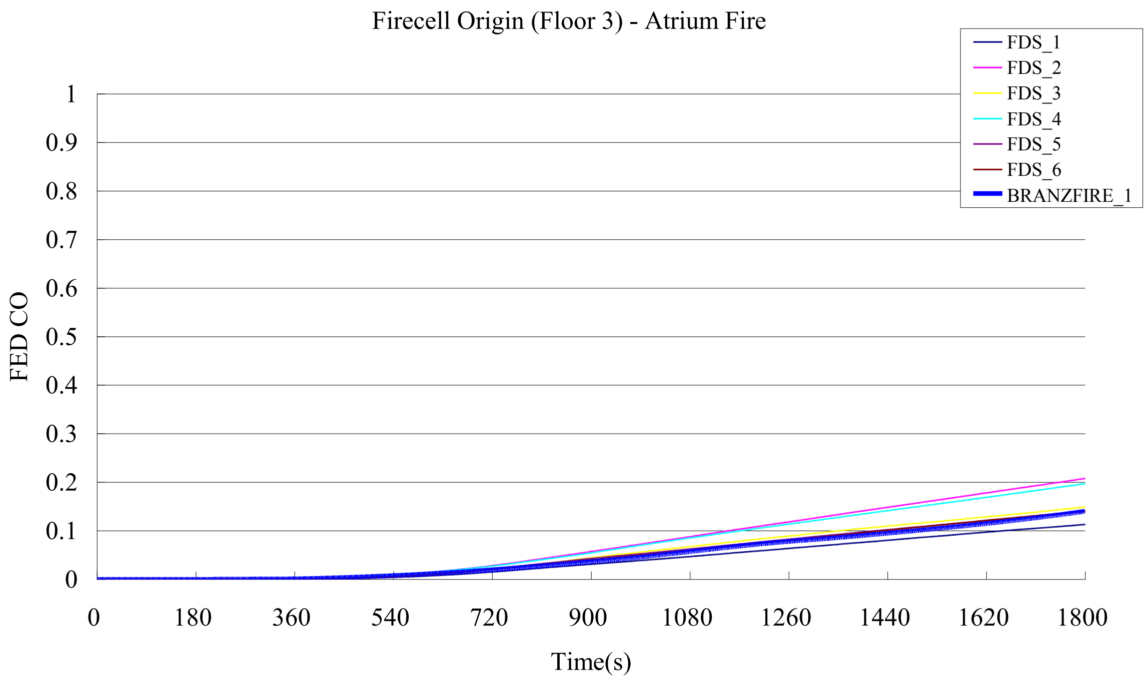
6. Shopping Mall – Atrium Fire

Device location:



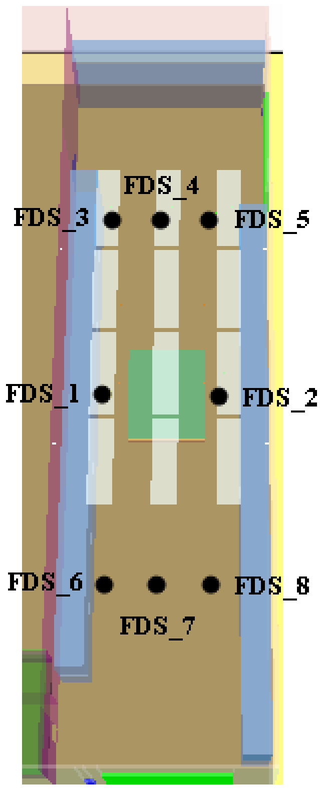

Firecell Origin (Floor 3) - Atrium Fire
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
BRANZFIRE_1
Visibility (m)
20
18
16
14
12
10
8
6
4
2
0
0
180
360
540
720
900
1080
1260
1440
1620
1800
Time(s)

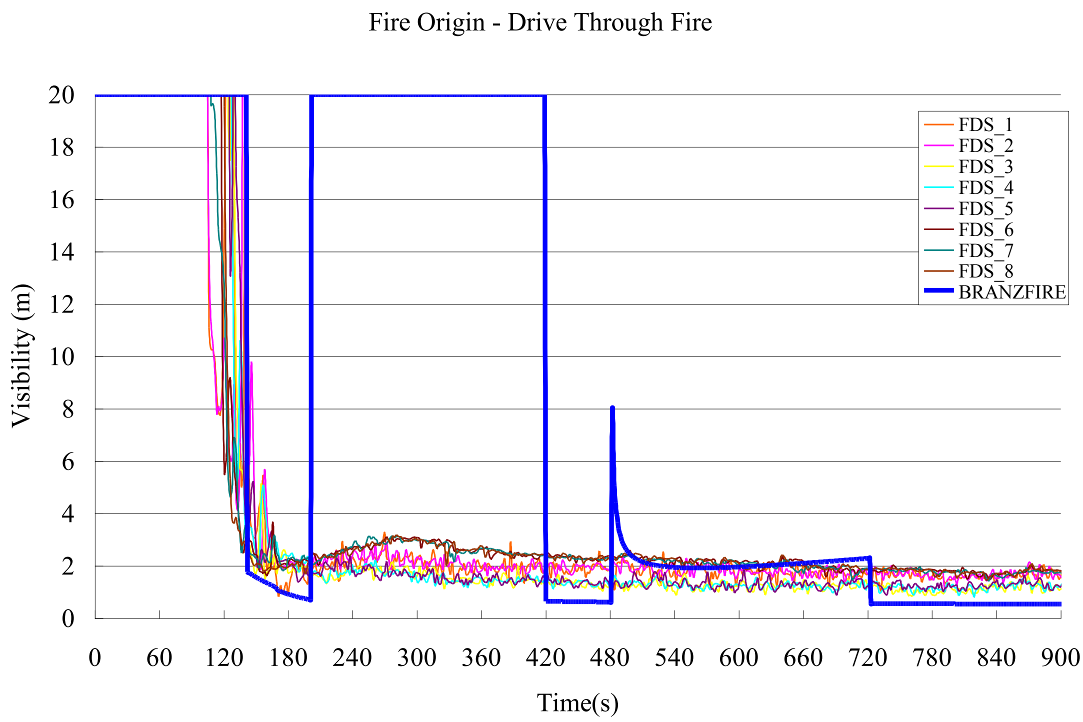

Firecell Origin (Floor 3) - Atrium Fire
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
BRANZFIRE_1
FED Thermal
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
180
360
540
720
900
1080
1260
1440
1620
1800
Time(s)



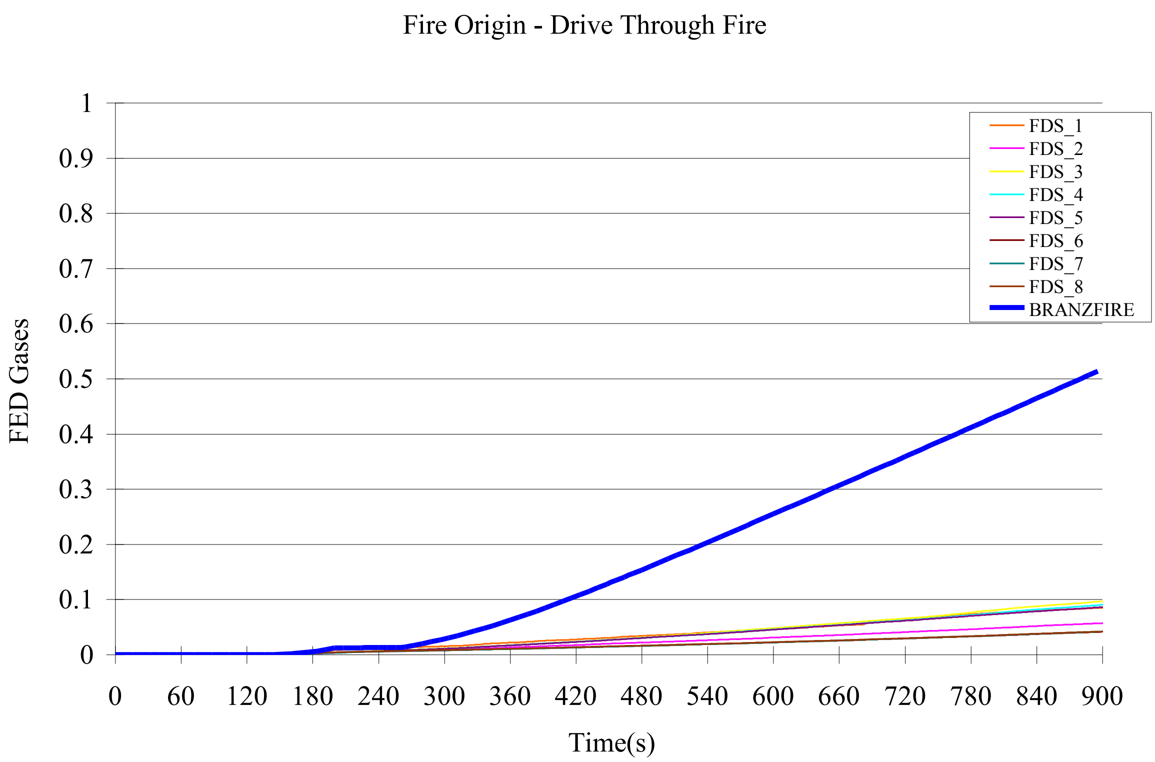
7. Retail Warehouse – Drive Through Fire

Device location:




Fire Origin - Drive Through Fire
Visibility (m)
20
18
16
14
12
10
8
6
4
2
0
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
FDS_7
FDS_8
BRANZFIRE


Fire Origin - Drive Through Fire
FED Thermal
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
FDS_7
FDS_8
BRANZFIRE


Fire Origin - Drive Through Fire
FED Gases
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
Time(s)
FDS_1
FDS_2
FDS_3
FDS_4
FDS_5
FDS_6
FDS_7
FDS_8
BRANZFIRE